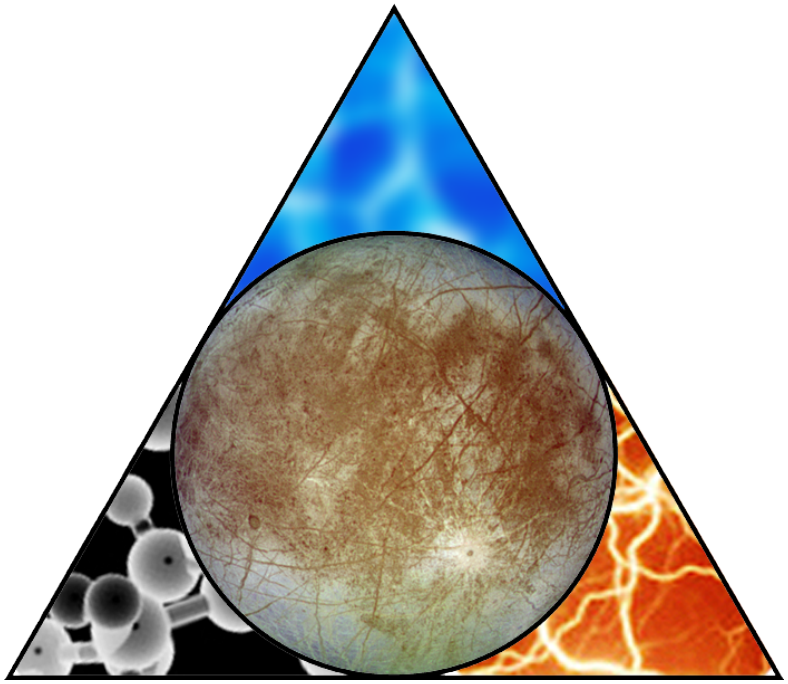
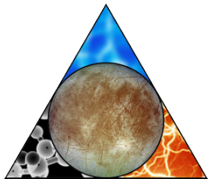


Europa Summary Study
Report to the Outer Planets Assessment Group

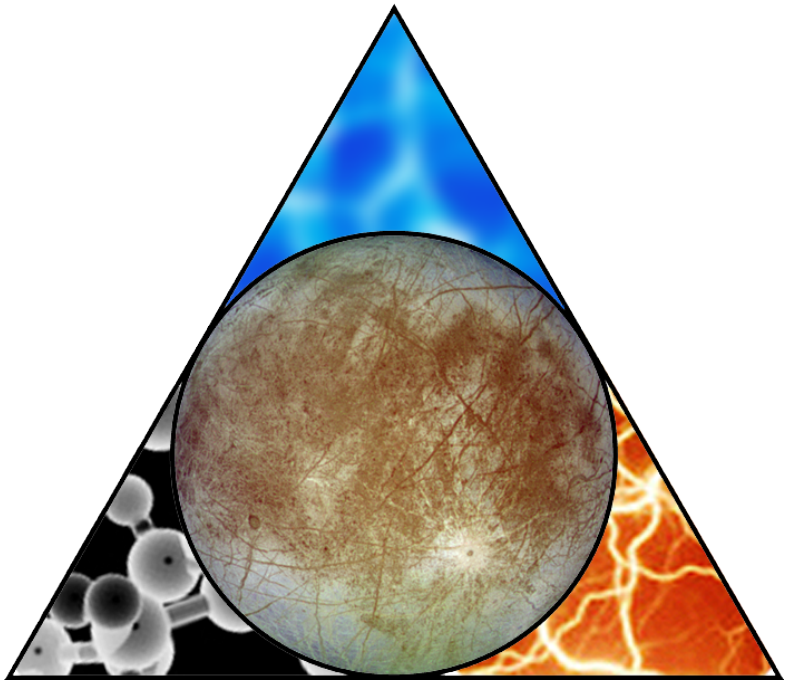
D. Senske[1], L. Prockter[2], B. Cooke[1], R. Pappalardo[1]
[1]Jet Propulsion Laboratory/California Institute of Technology,
[2]Applied Physics Laboratory/Johns Hopkins University

1/10/13

Agenda

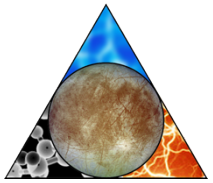


• Introduction/Charge from NASA	R. Pappalardo
• Science	D. Senske
• Reconnaissance	
• Enhanced Clipper	B. Cooke
• Enhanced Orbiter	
• Cost	
• SDT Recommendations	L. Prockter
• Reviews	D.Senske
• Path Forward	



Charge from NASA

Charge from NASA for Summer Study



Enhanced Clipper Science

- Examine the ability to address the Ocean science objectives with the Clipper mission option and understand implications for the mission design and number of flybys while remaining cost neutral ($2B, FY15$, excluding LV)

Enhanced Orbiter Science

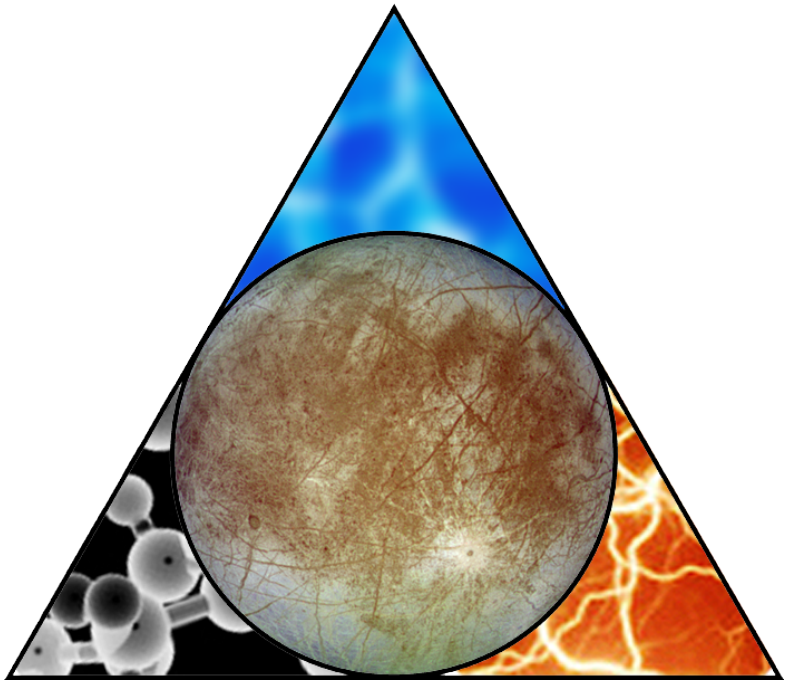
- Examine the ability to address the Ice Shell, Composition and/or additional Geology science objectives with the Orbiter mission option and understand implications for the mission design and spacecraft architecture. Remaining within the Clipper cost ($2B, $FY15, excluding LV)

Landing Site Reconnaissance

- Examination of the Landed Mission option in May identified surface condition uncertainty as a risk
- Examine capabilities that can be added to the current mission to mitigate concern for a future landed mission

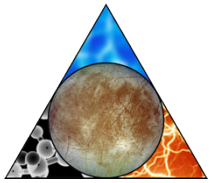
Engineering Trades

- Investigation of power options
- Assess the enabling benefits of the Space Launch System
- Examine the accommodation of potential nanosats and the science they could achieve



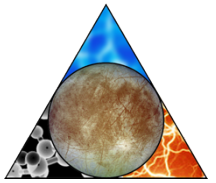
Science

Europa Enhancement Science Definition Team

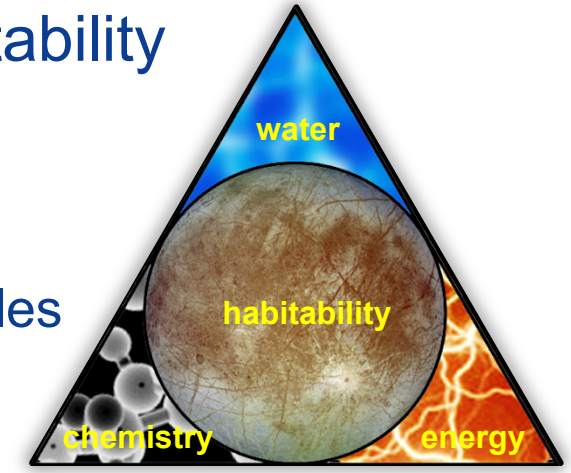


Fran Bagenal	Univ. Colorado	Space Physics
Bruce Bills	JPL	Geophysics
Diana Blaney	JPL	Composition
Don Blankenship	Univ. Texas	Ice shell
Will Brinckerhoff	GSFC	Astrobiology
Jack Connerney	GSFC	Magnetometry
Kevin Hand	JPL	Astrobiology
Tori Hoehler	Ames	Astrobiology
Bill Kurth	Univ. Iowa	Plasma
Melissa McGrath	MSFC	Atmosphere
Mike Mellon	SWRI	Ice Physics / Geology
Jeff Moore	Ames	Geology
Robert Pappalardo	JPL	On Sabbatical
Louise Prockter	APL	Chair / Geology
Dave Senske	JPL	Study Scientist / Geology
Everett Shock	ASU	Geochemistry
David Smith	MIT	Geophysics

Science Goal, Habitability Themes, and Objectives

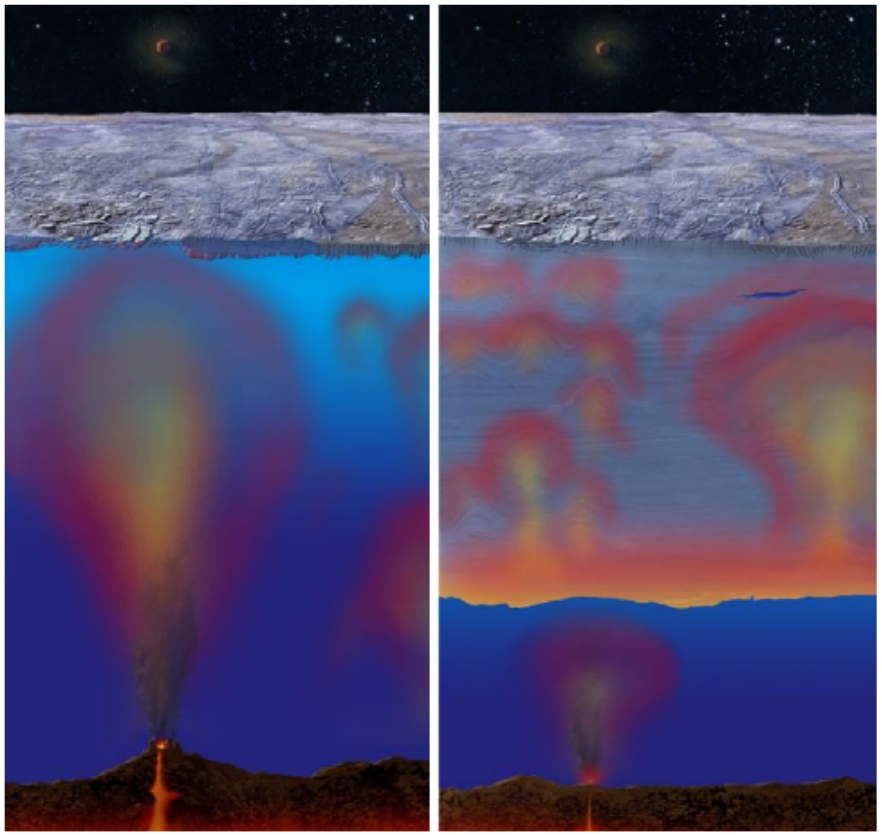


- *Goal:* Explore Europa to investigate its habitability
- *Habitability Themes:*
  - **Water:** Solvent to facilitate chemical reactions
  - **Chemistry:** Constituents to build organic molecules
  - **Energy:** Chemical disequilibrium for metabolism
- *Objectives:*
  - **Ocean:** Existence, extent, and salinity
  - **Ice Shell:** Existence and nature of water within or beneath, and nature of surface-ice-ocean exchange
  - **Composition:** Distribution and chemistry of key compounds and the links to ocean composition
  - **Geology:** Characteristics and formation of surface features, including sites of recent or current activity



Ocean • Ice Shell • Composition • Geology

Clipper May 2012 Report

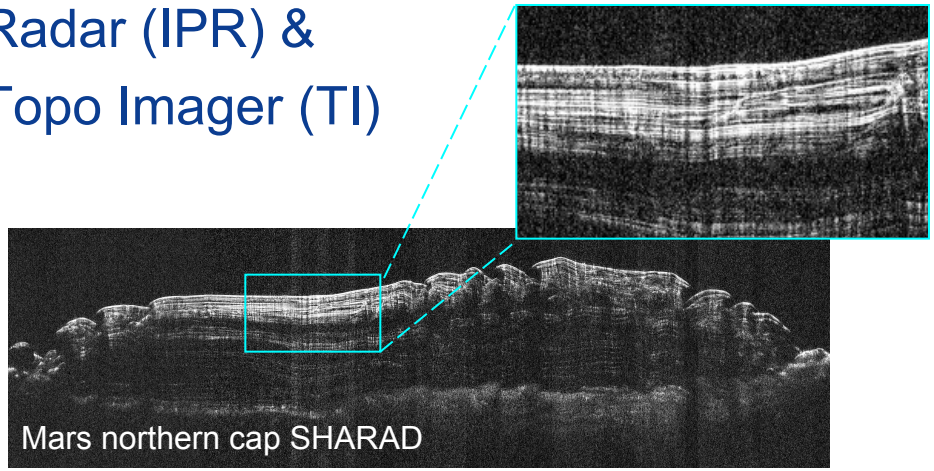


Ice shell:

- Shallow water
- Ice-ocean interface
- Material exchange
- Heat flow variations

Science achieved using Ice Penetrating Radar (IPR) &

Topo Imager (TI)



Radar sounding can characterize the ice shell

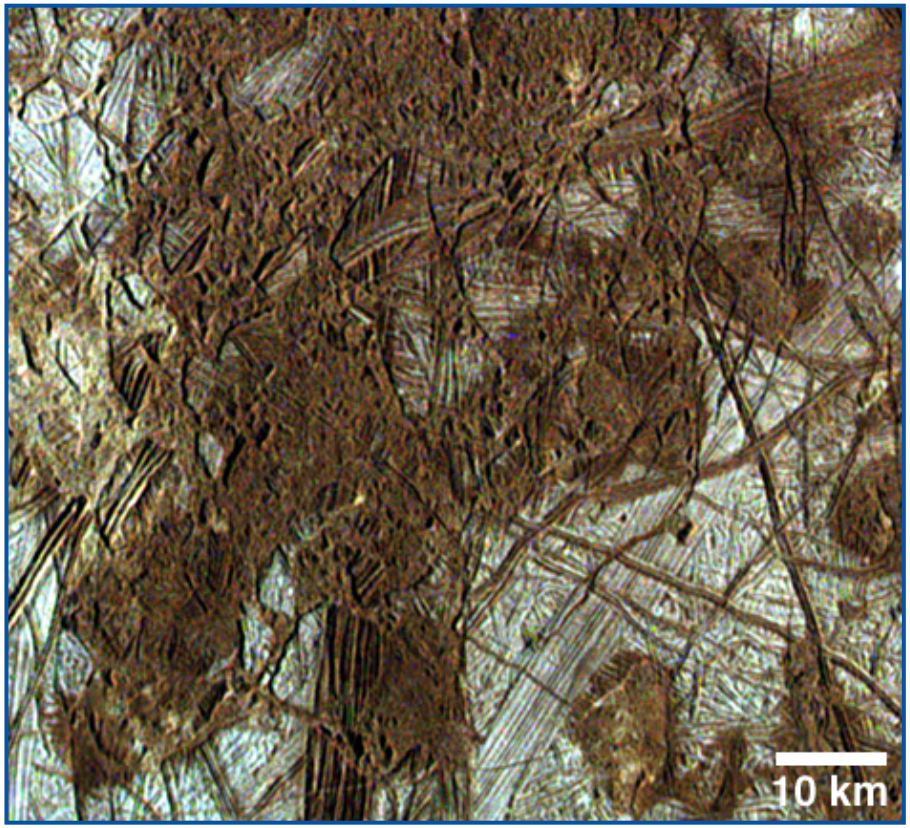
Ocean • Ice Shell • Composition • Geology

Clipper May 2012 Report

Composition & chemistry:

- Characterize composition and chemistry on surface and in atmosphere
- Radiation effects
- Chemical and compositional pathways in the ocean

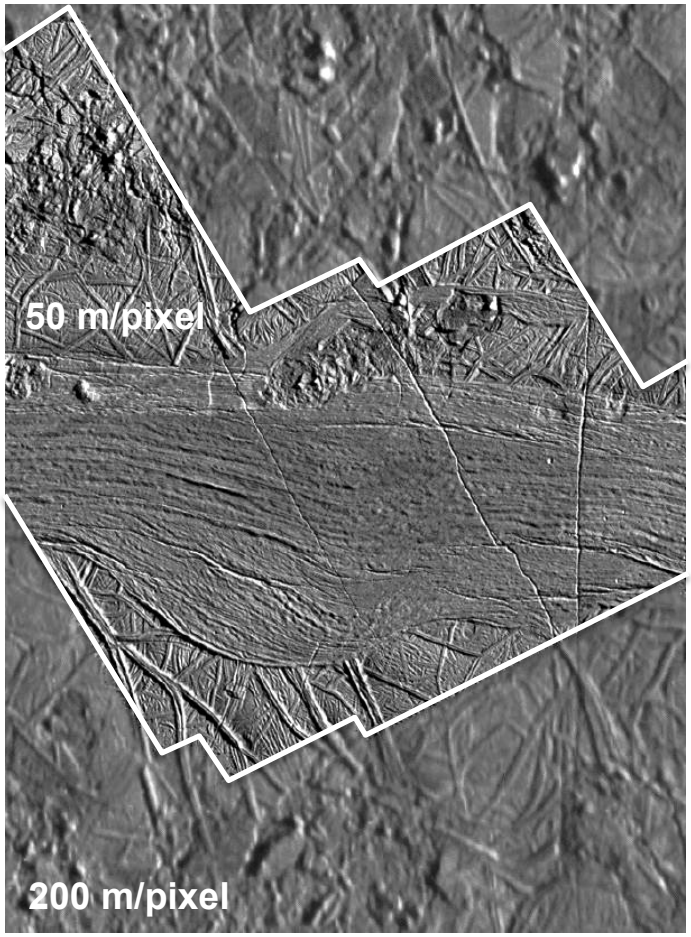
Science achieved using Short Wave Infrared Spectrometer (SWIRS) & Ion and Neutral Mass Spectrometer (INMS)



Composition is key to understanding Europa's habitability

Ocean • Ice Shell • Composition • Geology

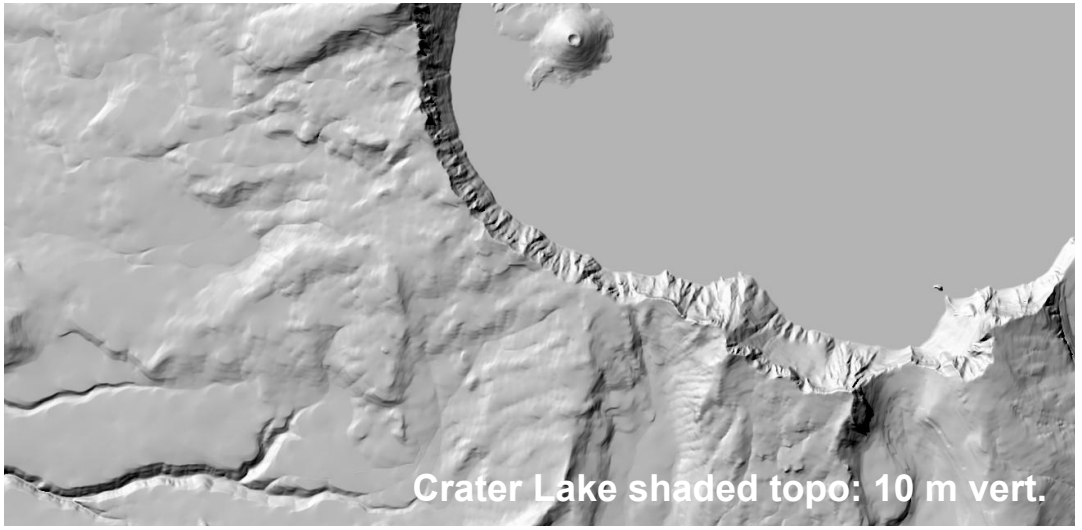
Clipper May 2012 Report



Surface features & activity:

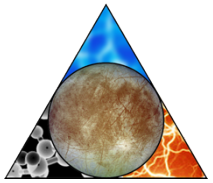
- Recent activity
- Characterize high-interest localities

Science achieved using Topographical Imager (TI): 25-200 m/pixel, 10 m vert.



Targeted landforms to decipher geological processes and activity

SDT Priority of Science Enhancements for Clipper



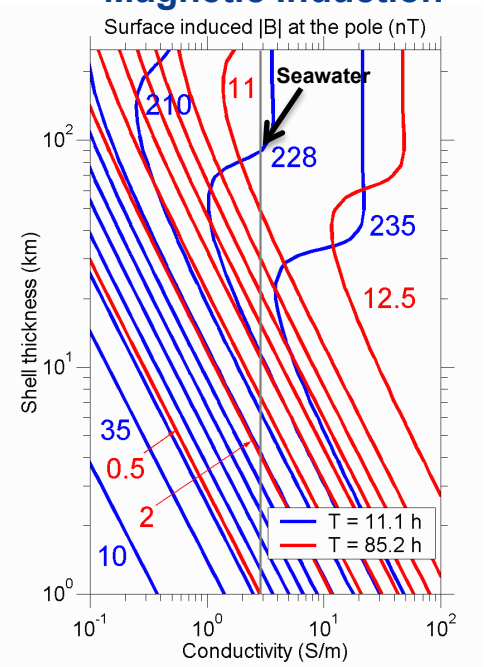
- Address Ocean science objectives while remaining cost neutral and optimize science
- Priorities:
  - Include means to acquire geophysical magnetic field and gravity data sets to provide insight into ocean salinity, thickness, and determine gravitation tides
    - Achieved through including Magnetometer and Langmuir Probe for magnetic field measurements and dedicated Doppler radio tracking for characterization of the gravity field
  - To remain cost neutral, descope the current Clipper Ion and Neutral Mass Spectrometer (INMS) to a Neutral Mass Spectrometer (NMS)

Desired Enhanced Clipper Science

- **Ocean**: Characterize the properties of the ocean
  - Determine Europa's magnetic induction response to estimate ice shell thickness, and ocean salinity and thickness
  - Determine the amplitude and phase of gravitational tides

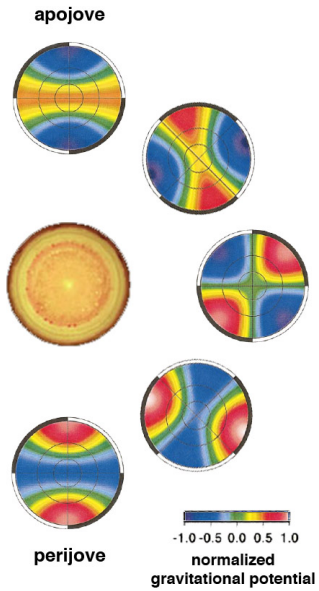
Providing an understanding of the properties of the ocean

Magnetic Induction



From Khurana 2002

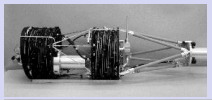
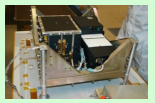
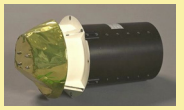
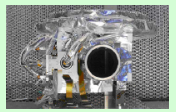
Gravitational Tides



From: Moore and Schubert [2000]

- **Geology**: Expand observation strategy to achieve global & regional along with the local coverage

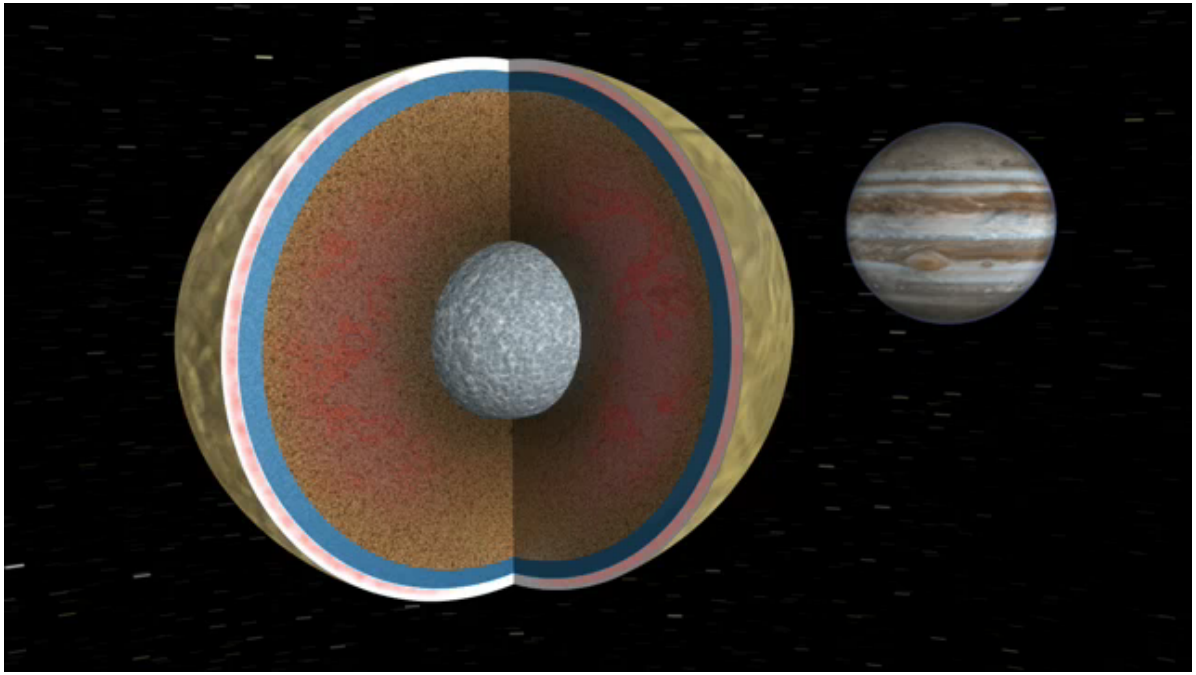
Clipper key Science Investigations and Enhanced Model Planning Payload

Science Objective	Key Science Investigations	Model Instrument	Similar Instrument
Ocean & Ice Shell	**Time-varying gravity field through Doppler tracking, to detect ocean and determine interior structure.**	**Radio Sub-system (RS); Independent Gimbaled Antenna**	
	Magnetic induction response, to derive ocean thickness and salinity. Local plasma and electric field, to support magnetic induction experiment.	**Magnetometer (MAG) with Langmuir Probe (LP)**	**Juno MAG**  **Rosetta LAP** 
	Sounding of dielectric horizons at two frequencies, to search for shallow water and the ocean.	Ice-Penetrating Radar (IPR)	MRO SHARAD 
Composition	Visible and near-infrared spectroscopy, for global mapping and high-resolution scans, to derive surface composition.	ShortWave IR Spectrometer (SWIRS)	LRO M3 
	Elemental, isotopic, and molecular composition of the atmosphere and ionosphere, during close flybys.	Neutral Mass Spectrometer (NMS)	Nozomi 
Geology	**Medium to** High resolution stereo imagery, to characterize geological landforms, and to remove clutter noise from IPR data.	Topographical Imager (TI)	 New Horizons Ralph/ MVIC

Floor model instrument | Baseline model instrument | **Enhancement**

Ocean & deeper interior:

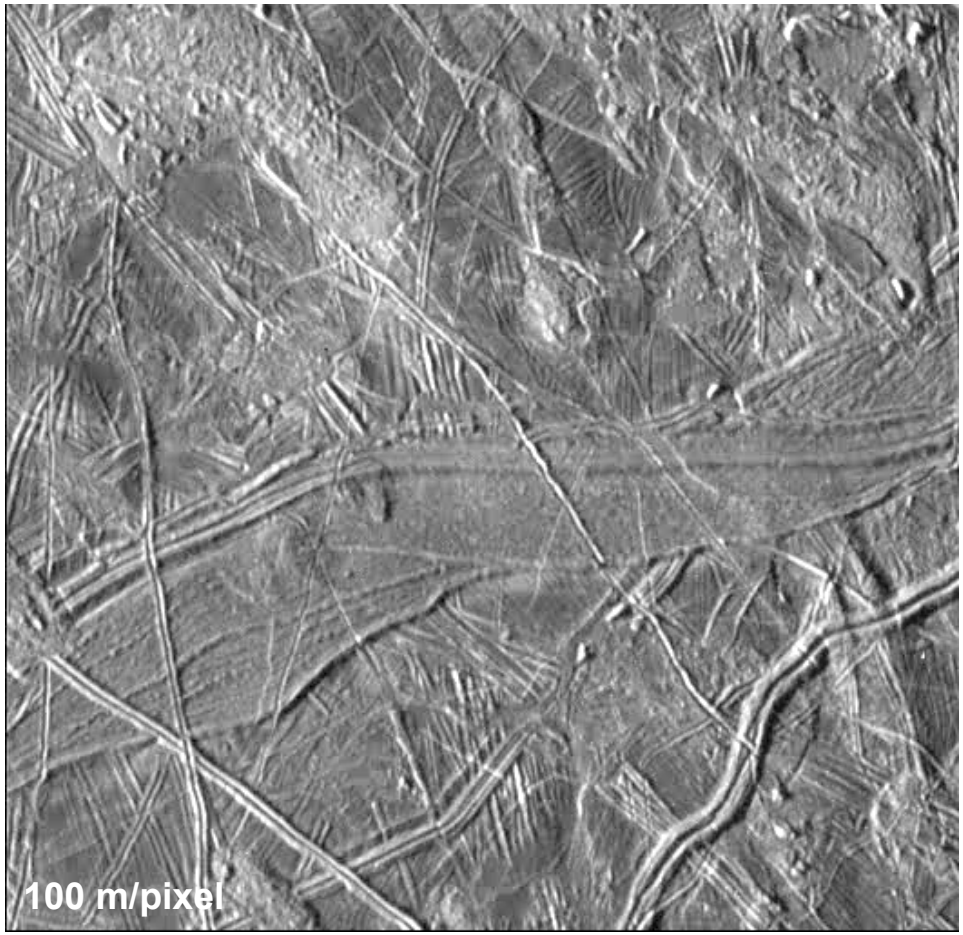
- Gravitational tides—
  Radio Subsystem (RS)
- Magnetic induction (including plasma)—
  Magnetometer (MAG) & Langmuir probe (LP)
- Topographic tides—
  Laser Altimeter (LA)
- Rotation state—
  Laser Altimeter (LA)
- Deeper interior—
  Radio Subsystem (RS)



Geophysical techniques reveal the interior

Ocean • Ice Shell • Composition • Geology

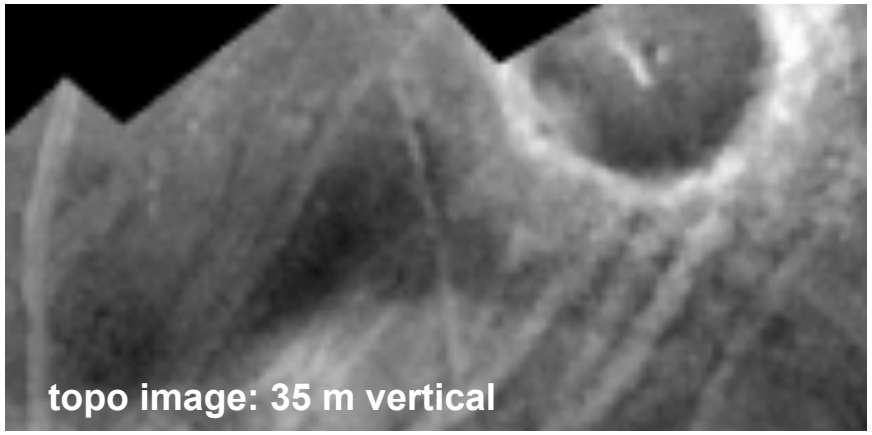
Orbiter May 2012 Report



Surface features & activity:

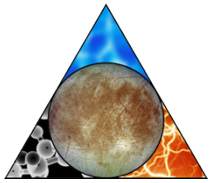
- Distribution, formation, and three-dimensional characteristics of magmatic, tectonic, and impact landforms

Science achieved using Mapping Camera (MC): 100 m/pixel, 25 m vert.)



Europa's varied and complex geology can be unraveled

SDT Priority of Science Enhancement for Orbiter



- Address Ice Shell, Composition and/or additional Geology
- Priorities:

Pathway #1 (Highest priority):

(1) Attempt to achieve Ice Shell science through the inclusion of an Ice Penetrating Radar (IPR)

(2) If it is possible to accommodate the IPR and resources remain, attempt to include Composition science through the inclusion of a "simplified" ShortWave Infrared Spectrometer (SWIRS)—the SWIRS from the Clipper concept was a significantly descoped instrument and it was concluded there were no additional ways to simplify it and thus, the SWIRS is the floor instrument

Pathway #2 (Lower priority):

If it is not possible to do Pathway #1, then attempt to achieve (in priority order) some Composition science with the SWIRS and/or Neutral Mass Spectrometer (NMS)

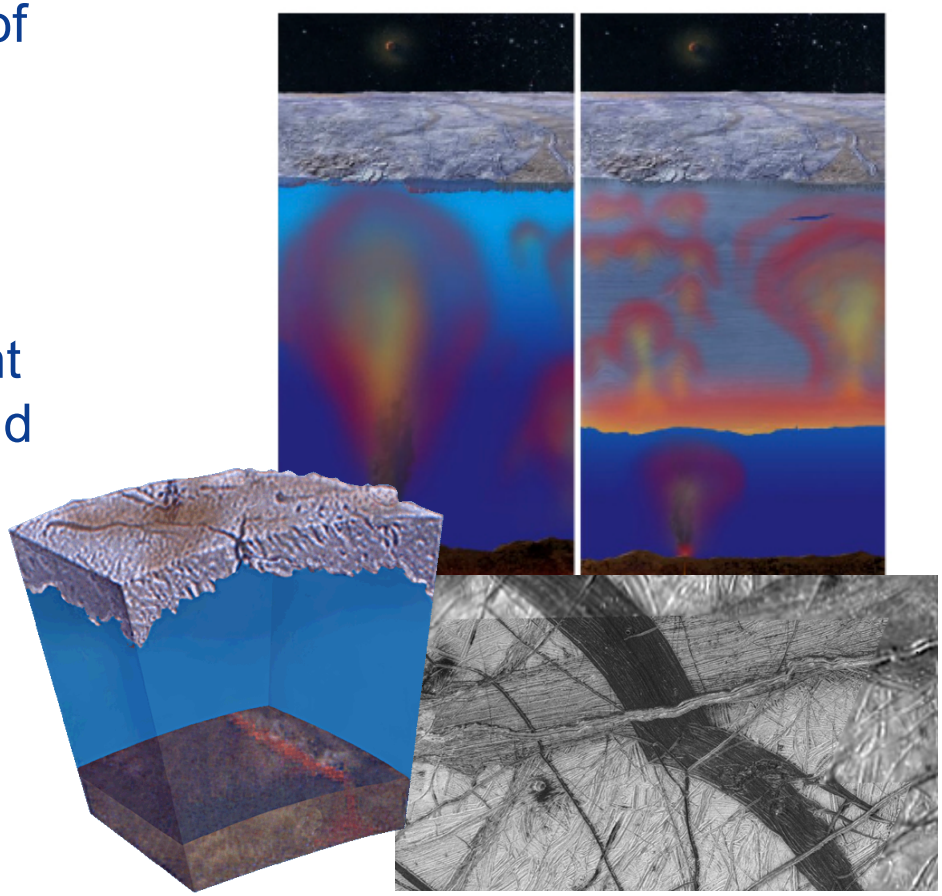
In addition, attempt to achieve a single aspect of Ice Shell science by searching for endogenic hotspots through the inclusion of a Thermal Instrument

Desired Enhanced Orbiter Science

- **Ocean:** Characterize the extent of the ocean and its relation to the deeper interior
- **Geology**: Understand the formation of surface features, including sites of recent or current activity to understand regional and global evolution

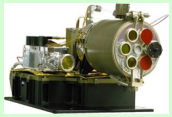
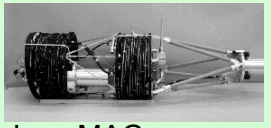
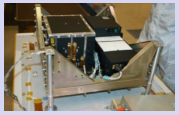
***Science Enhancement*:**

- **Ice Shell:** Characterize the ice shell and any subsurface water, including their heterogeneity, and the nature of surface-ice-ocean exchange



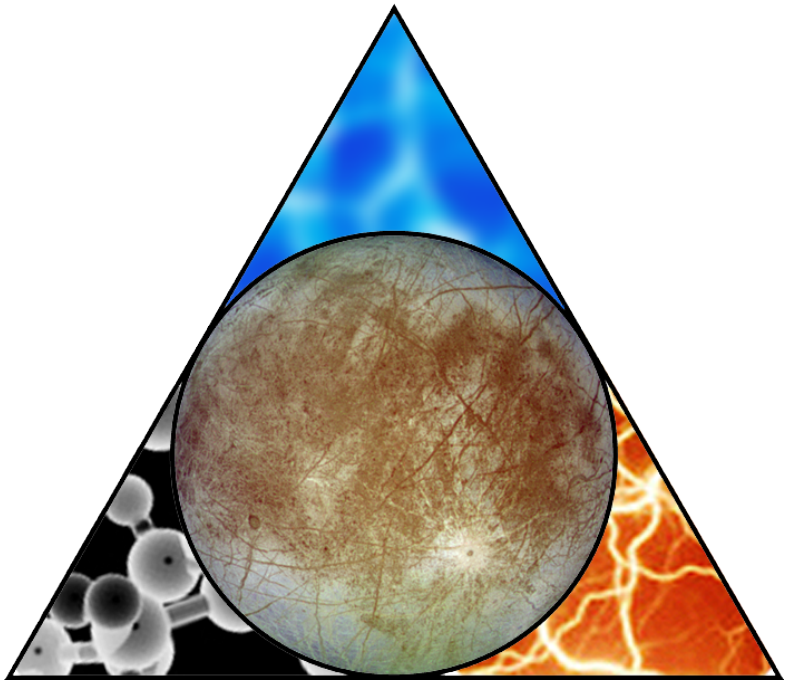
Focus on providing a comprehensive understanding of the ocean and its tidal interaction with the icy crust

Orbiter key Science Investigations and Enhanced Model Planning Payload

Science Objective	Key Science Investigations	Model Instrument	Similar Instrument
Ocean	Time-varying gravity field through Doppler tracking, to detect ocean and determine interior structure.	**Radio Sub-system (RS)**	
	Time-varying tidal amplitude, to detect ocean and determine interior structure.	**Laser Altimeter (LA)**	 NEAR NLR
	Magnetic induction response, to derive ocean thickness and salinity.	**Magnetometer (MAG)**	 Juno MAG
	Local plasma and electric field, to support magnetic induction experiment.	**Langmuir Probe (LP)**	 Rosetta LAP
Ice Shell	**Sounding of dielectric horizons at two frequencies, to search for shallow water and the ocean.**	**Ice-Penetrating Radar (IPR)**	 **MRO SHARAD**
Geology	Uniform global mapping, for landform global distribution and stratigraphy.	**Mapping Camera (MC)**	 MPL/MSL MARDI

Note: Model instrument baseline and floor are equivalent

Enhancement

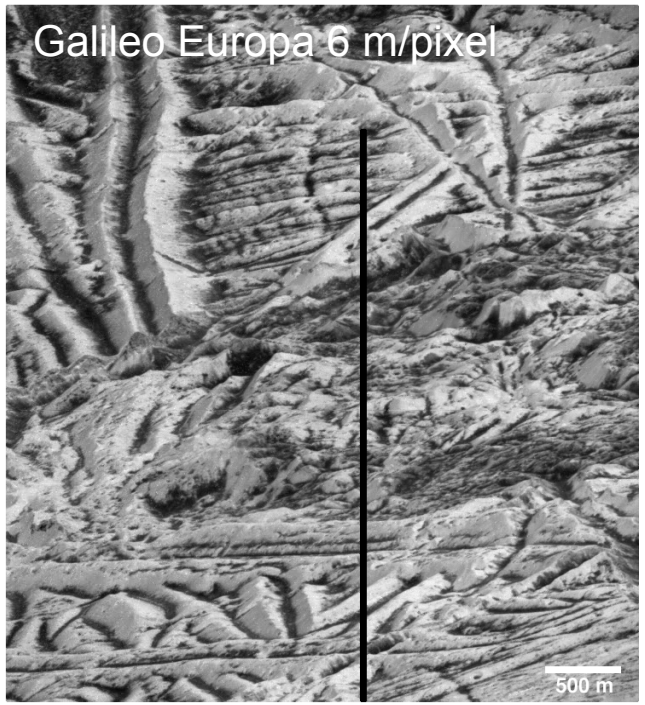


Reconnaissance

Programmatic Need for Feed Forward Reconnaissance Data Sets

- Reconnaissance data is necessary from both science and engineering perspectives:
  - *Science reconnaissance for landing site selection (enabled by the current model payload)*
    - Is the landing site scientifically compelling in addressing the goal of exploring Europa to investigate its habitability
  - *Engineering reconnaissance for landing safety*
    - Is a safe landing site (within the lander's design margins) accessible to a spacecraft?
    - Assess 15 sites to determine conditions and find two that are safe

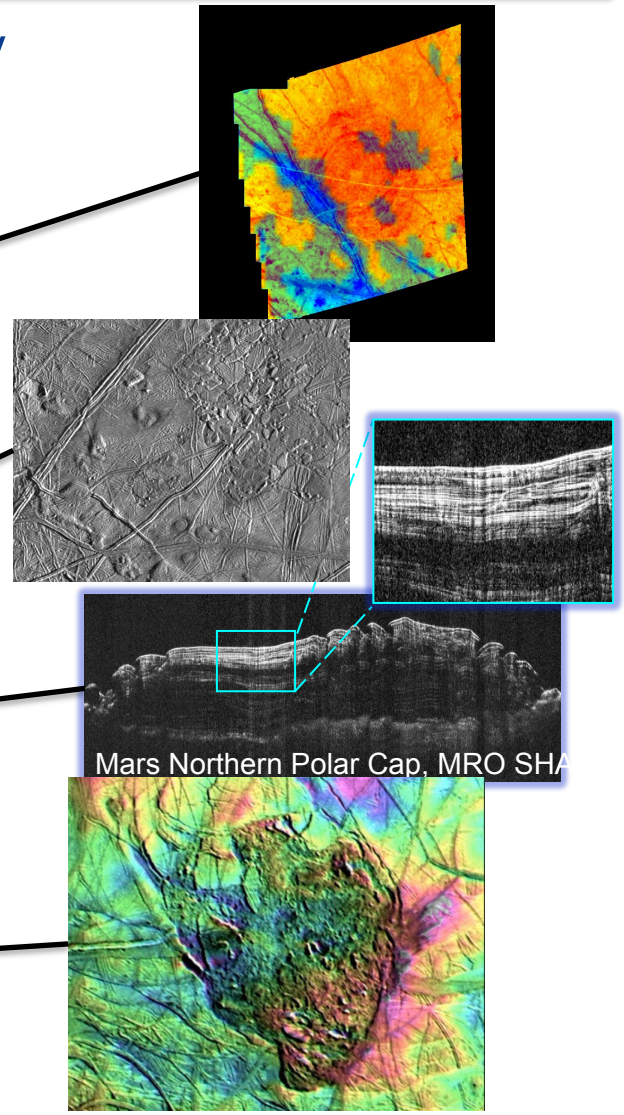
Highest Resolution Europa image currently available



Programmatic Need for Feed Forward Reconnaissance Data Sets

- Types of data required for selecting a scientifically compelling landing site

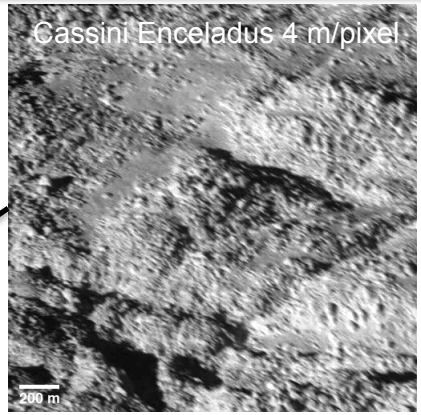
Observation	Landing Site Selection Goal
Spectroscopic Imaging **(Clipper)**	- Identify sites of compositional interest for habitability. - Identify concentration and local variability, ocean representation, and recent extrusion.
Context Imaging **(Clipper)**	-Identify context to global scale geologic processes -Identify sites of recent geologic activity, relation to subsurface extrusions and upwelling.
Sounding Radar **(Clipper; Augmented Orbiter)**	Identify sites proximal to shallow liquid water and potential for recent extrusion of ocean material.
Stereo Imaging (Context and HiRes) **(Partially covered by Augmented Clipper & Orbiter)**	- Understand the relative uplift and subsidence processes that relate the site to subsurface exchange. - Characterize local slopes that drive mass movement and landform development.

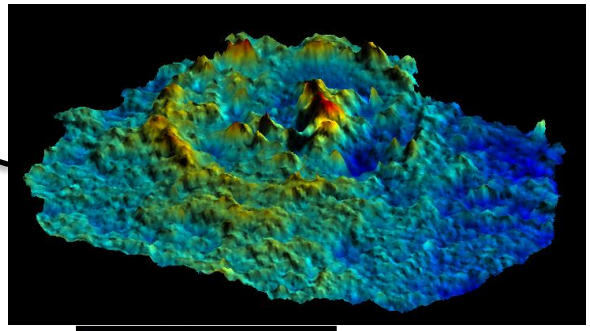


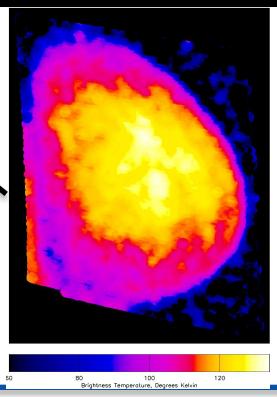
Programmatic Need for Feed Forward Reconnaissance Data Sets

- Types of data required for landing safety

Observation	Purpose
High Resolution Imaging	Map block abundance. Characterize ≥ meter-scale surface roughness.
Stereo Imaging	Maps surface slopes for lander tilt hazard, terrain relative navigation.
Thermal IR Imaging (Brightness Temperature and Bolometric Albedo*)	Verify visible block abundance & extrapolate to submeter scale. Validate average surface roughness & extrapolate. Identify regolith cover.







Galileo PPR

- Engineering Reconnaissance capabilities would also serve to reinforce the landing site scientific rationale

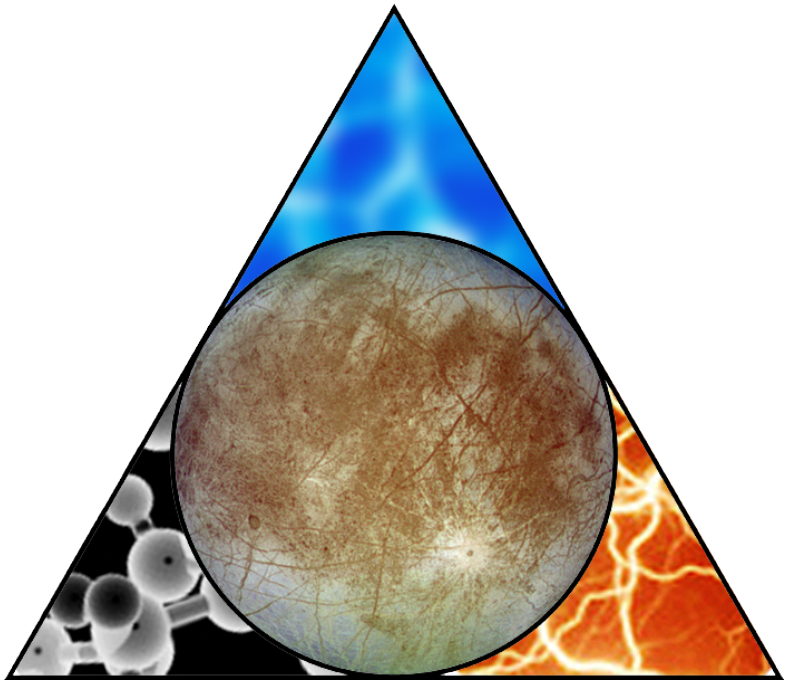
Programmatic Need for Feed Forward Reconnaissance Data Sets

Clipper

- The Clipper notional remote sensing payload (SWIRS, TI, IPR) provides a primary basis for selecting a scientifically compelling landing site
- Enhanced Clipper reconnaissance capability would include key elements to complete the reconnaissance data set needs
  - High resolution imaging at ~0.5 m/pixel
  - Thermal imaging might provide knowledge of the properties of the surface (if it can be accommodated)

Orbiter

- Existing Orbiter Laser Altimeter and Mapping Camera provide some reconnaissance benefit
- Enhanced Orbiter IPR and high resolution imaging would provide additional reconnaissance data
  - Thermal imaging could not be accommodated (due to mass & cost)



Europa Enhanced Clipper

Baseline Clipper in a Nutshell

May 2012

Science:

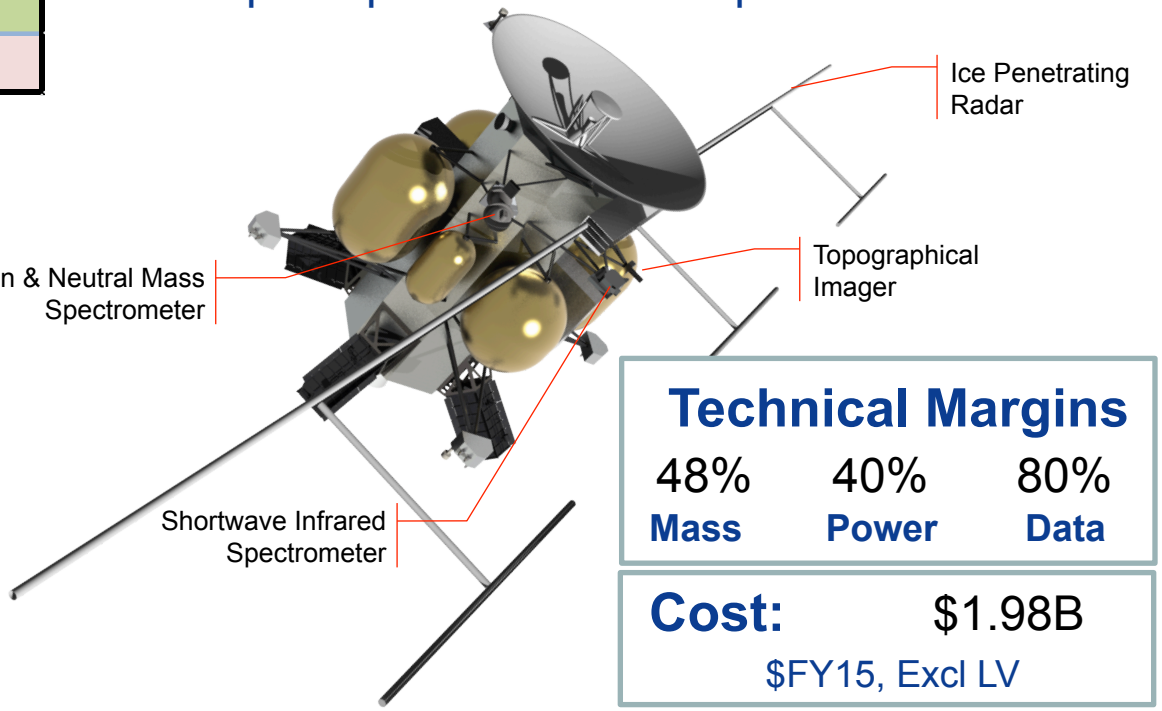
Objective	Clipper Baseline
Ice Shell	√
Ocean	X
Composition	√
Geology	√
Recon	X

Payload:

Instrument	Clipper Baseline
Floor	IPR
	SWIRS
	TI
Baseline	INMS

Operations Concept:

- 32 low altitude flybys of Europa from Jupiter orbit over 2.3 years
- Detailed investigation of globally distributed regions of Europa
- Simple repetitive science operations



Technical Margins

48%	40%	80%
Mass	**Power**	**Data**

Cost: $1.98B

$FY15, Excl LV

Enhanced Clipper Key Outcomes

Charge from SDT:

- ✔ Enhance May 2012 Baseline Clipper Mission to address Ocean objectives by including Magnetometry and Gravity Science instruments
- ✔ Reduce measurement requirements of the Ion Neutral Mass Spectrometer (INMS) to allow use of lower cost Neutral Mass Spectrometer (NMS) instrument
- ✔ Accommodate high resolution Reconnaissance Camera and Thermal Imager to enable feed forward reconnaissance data

Objective	Clipper Baseline
Ice Shell	√
Ocean	X
Composition	√
Geology	√
Recon	X

Objective	Clipper Enhanced w Recon
Ice Shell	√
Ocean	√
Composition	√
Geology	√
Recon	√

Enhanced Clipper w/ Recon

Science:

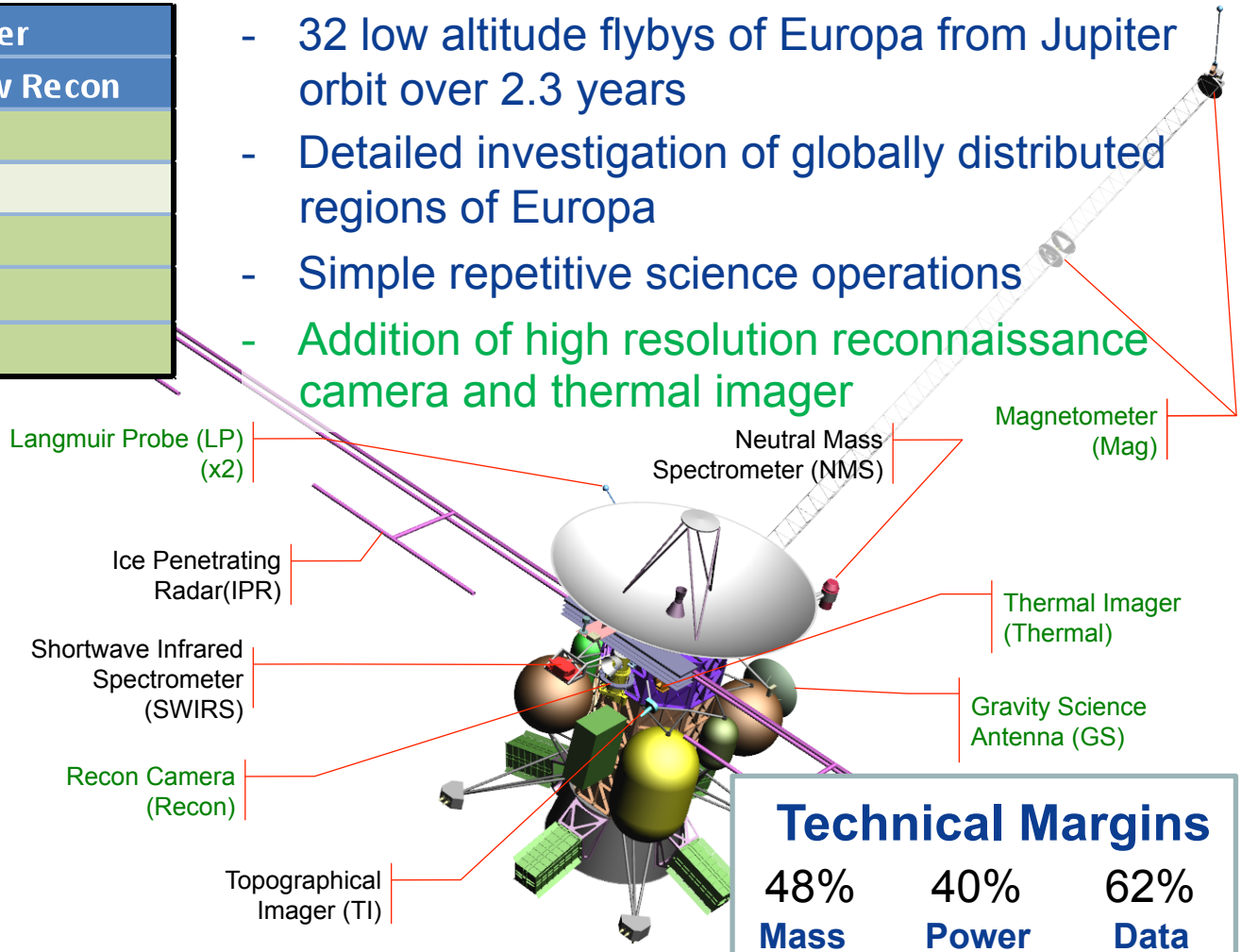
Objective	Clipper Enhanced w Recon
Ice Shell	√
Ocean	√
Composition	√
Geology	√
Recon	√

Payload:

Instrument	Clipper Enh w Recon
Floor	IPR
	SWIRS
	TI
Baseline	NMS
	MAG
	LP
	GS
	Recon
	Thermal

Operations Concept:

- 32 low altitude flybys of Europa from Jupiter orbit over 2.3 years
- Detailed investigation of globally distributed regions of Europa
- Simple repetitive science operations
- Addition of high resolution reconnaissance camera and thermal imager



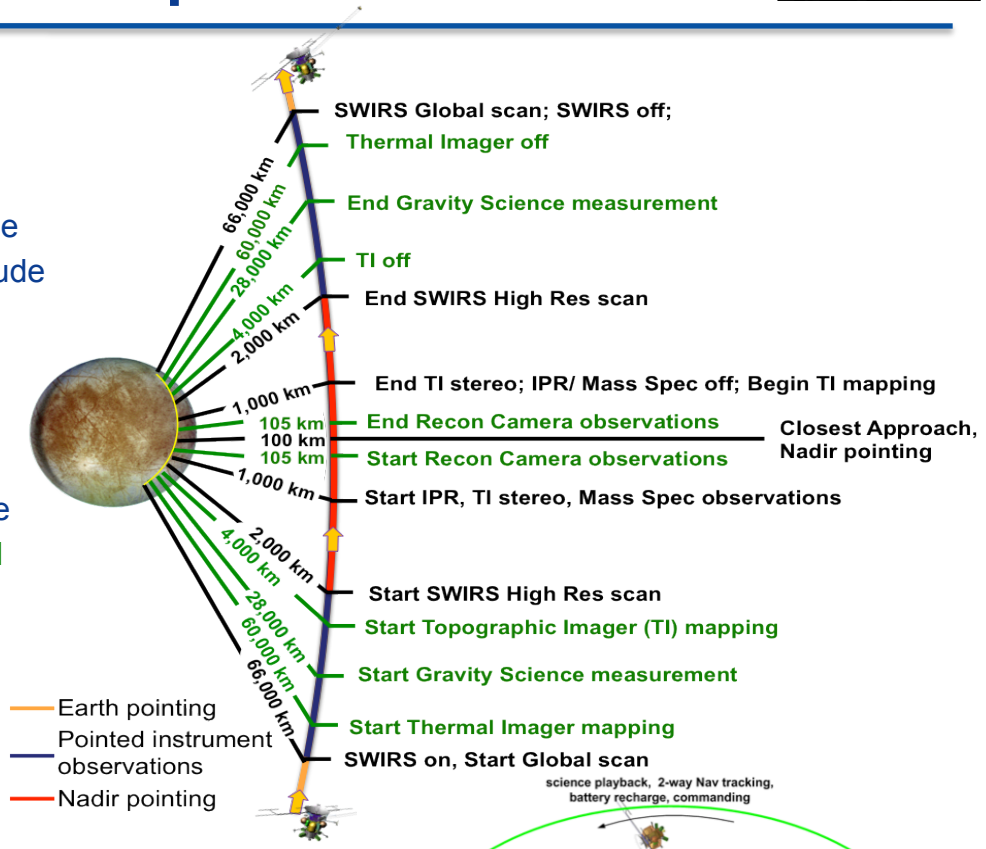
Technical Margins

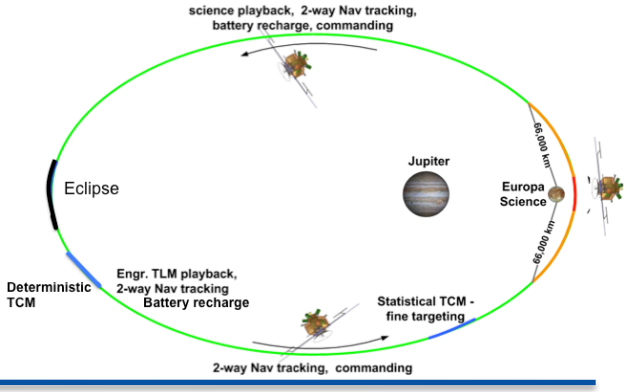
48%	40%	62%
Mass	**Power**	**Data**

Clipper Operations Concept
Simple and Repetitive

1. **Magnetometer and Langmuir Probes**
   - Continuous measurements
2. **ShortWave InfraRed Spectrometer (SWIRS)**
   - Global low resolution scan below 66,000 km altitude
   - Targeted high resolution scan below 2,000 km altitude
   - Passive below 1,000 km altitude
3. **Gravity Science**
   - Measurements below 28,000 km altitude
4. **Topographical Imager (TI)**
   - Pushbroom stereo imaging below 1,000 km altitude
   - Lower res. pushbroom imaging between 4,000 and 1,000 km altitude
5. **Ice Penetrating Radar (IPR)**
   - Surface scans below 1,000 km altitude
6. **Mass Spectrometer (NMS)**
   - *In situ* scan below 1,000 km altitude
7. **Recon Camera**
   - High resolution imaging below 105 km altitude
8. **Thermal Imager**
   - Pushbroom thermal imaging below 60,000 km

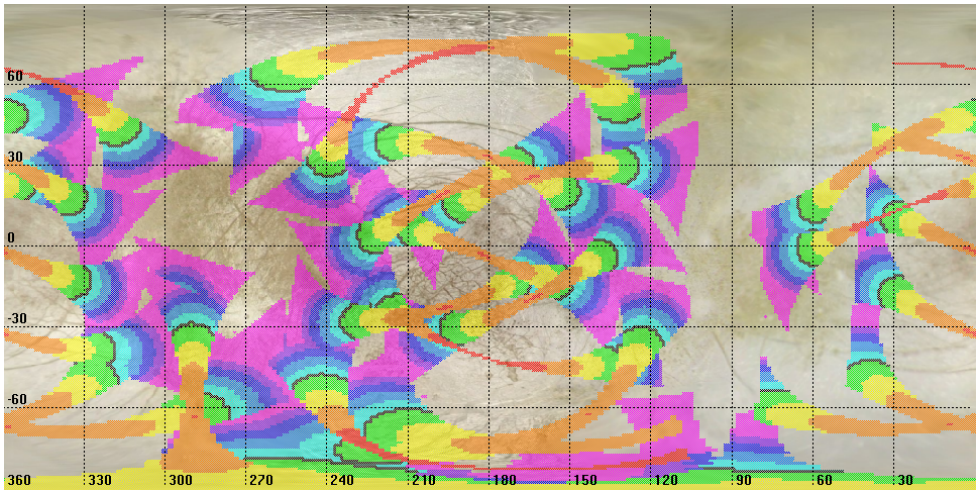
** May 2012 Clipper
** Enhanced Clipper

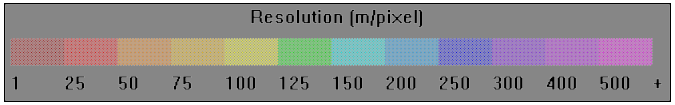




Enhanced Topographic Imager Coverage

BEFORE: Altitudes of C/A -1,000 km

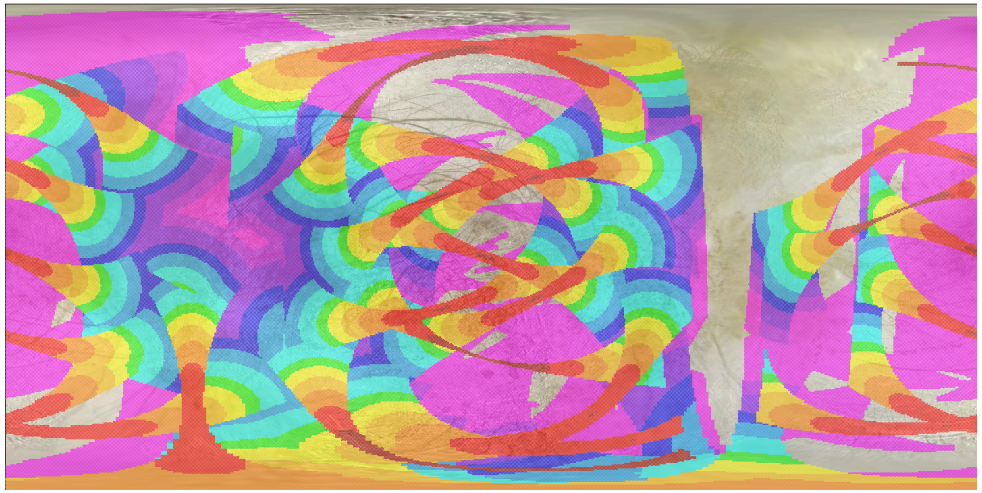




- One of the enhanced science objectives was to expand observation strategy to achieve regional geology coverage along with the local coverage

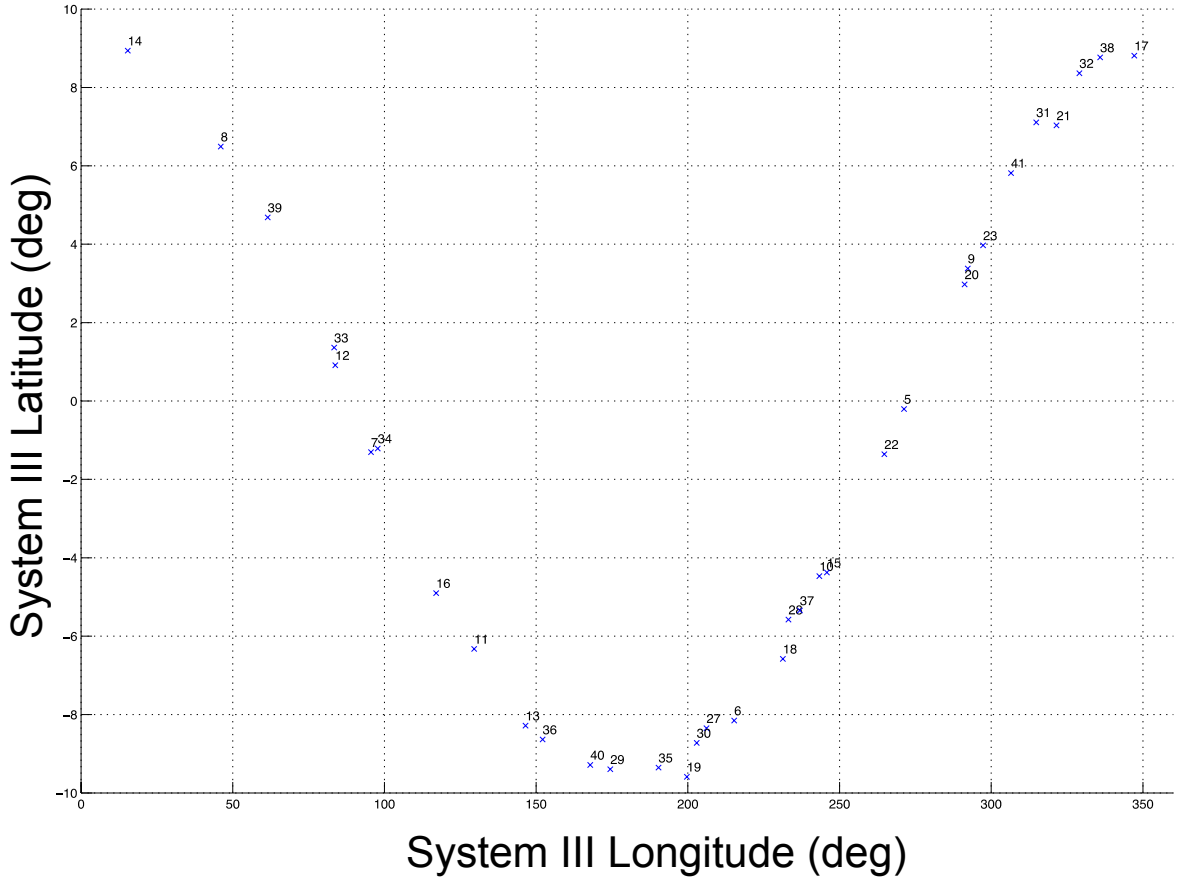
- In particular, the addition of the medium resolution stereo imagery to the already obtained TI data set
- Easily accommodated in 11-F5 trajectory with new coverage map shown on the right

AFTER: Altitudes of C/A -4,000 km



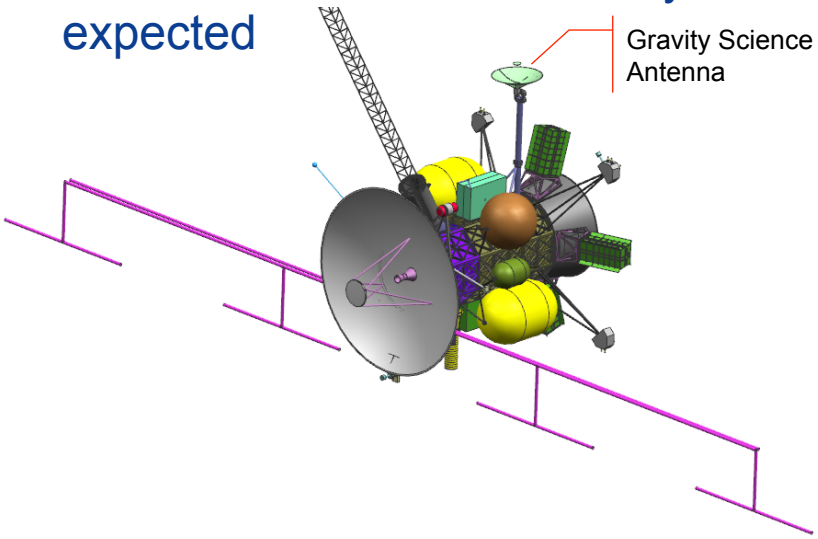
Magnetometry

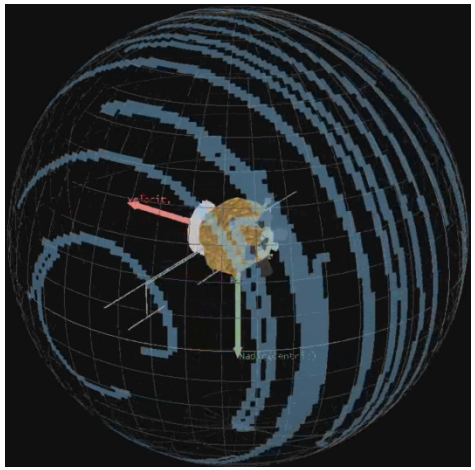
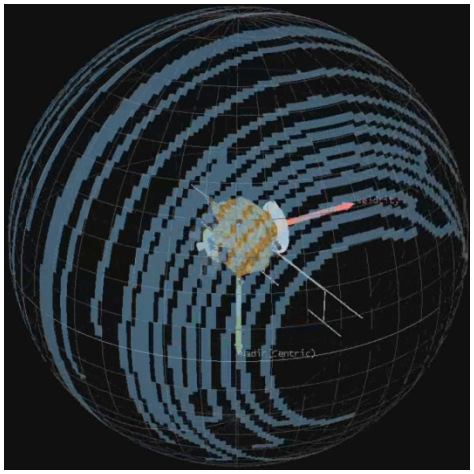
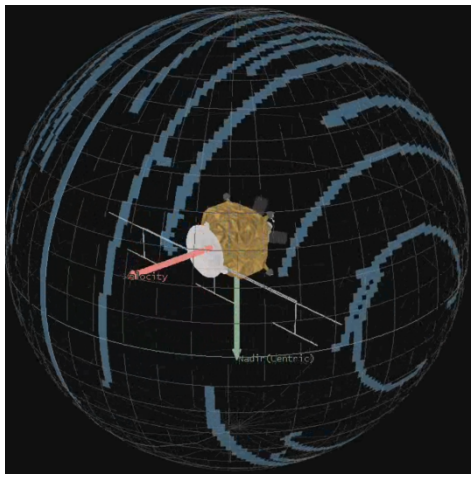
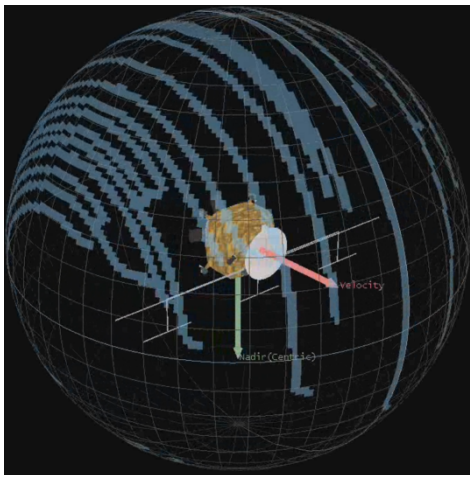
- Simulations suggest the 11-F5 trajectory can resolve Europa's conductance (product of ocean thickness and salinity)
- No trajectory modifications are necessary



Gravity Science Accommodation

- Flybys for 11-F5 trajectory were modeled in STK
- Earth traces were plotted from 28,000 km – C.A. – 28,000 km
- Earth traces span 360 degrees about the SC X-axis and nearly 290 degrees about the SC Z-axis
- Even with a gimballed antenna, some obscuration of Earth by s/c is expected

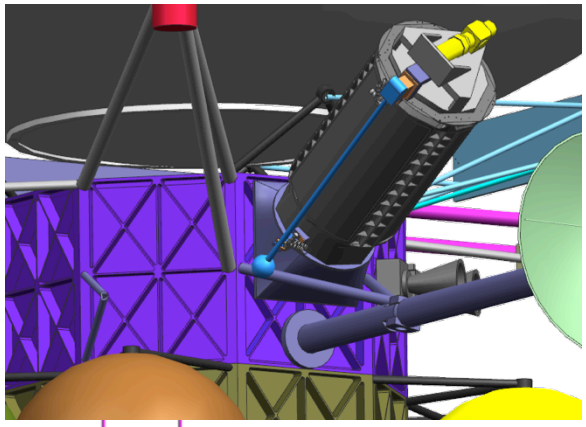


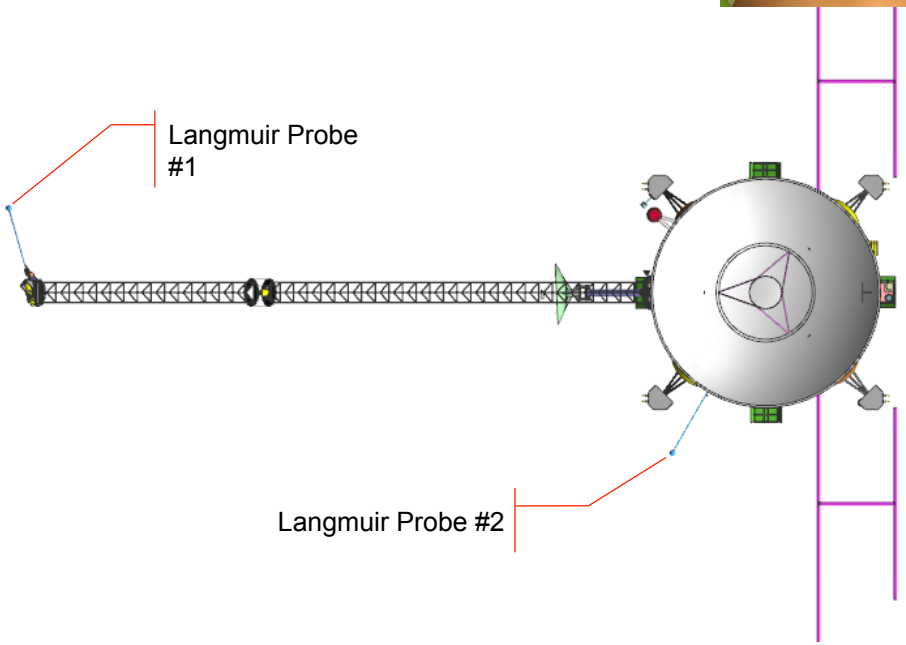





*model does not show Mag boom

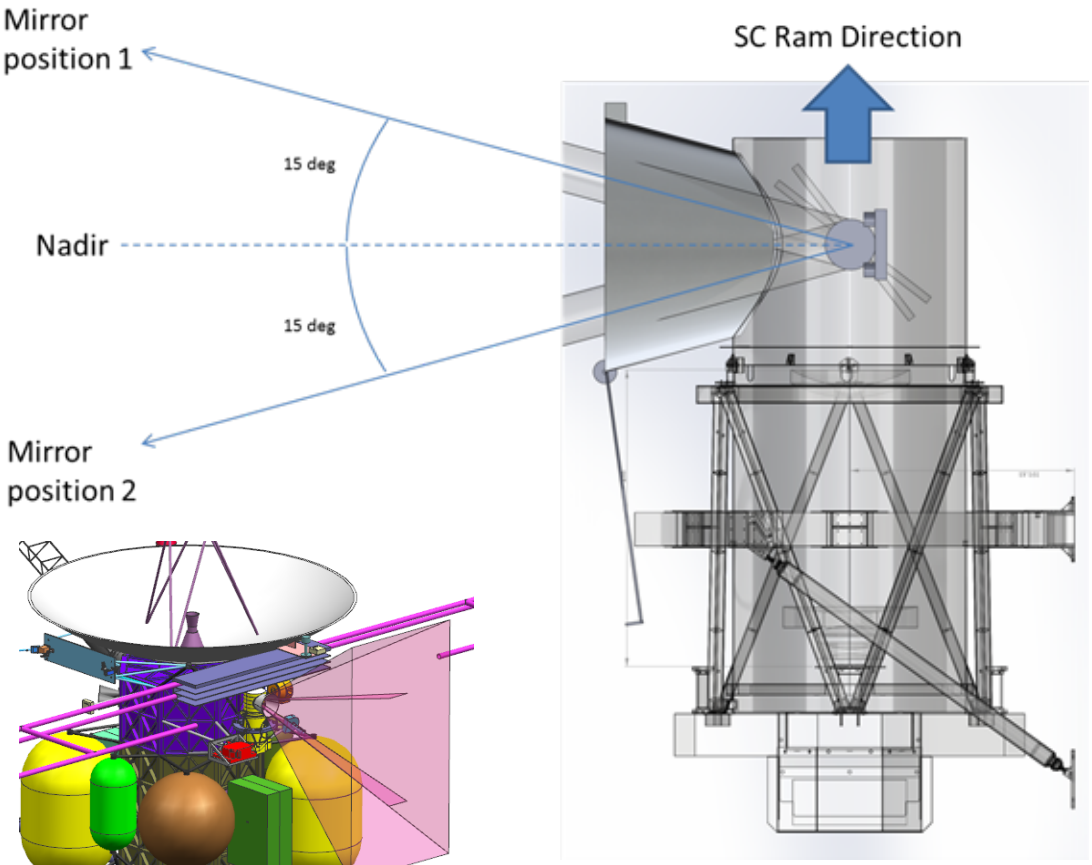
Langmuir Probe Accommodation

- Added 2 Langmuir Probes to spacecraft
- One probe mounted at the end of the magnetometer boom to clear the SC wake
- The shown configuration affords optimal wake clearance

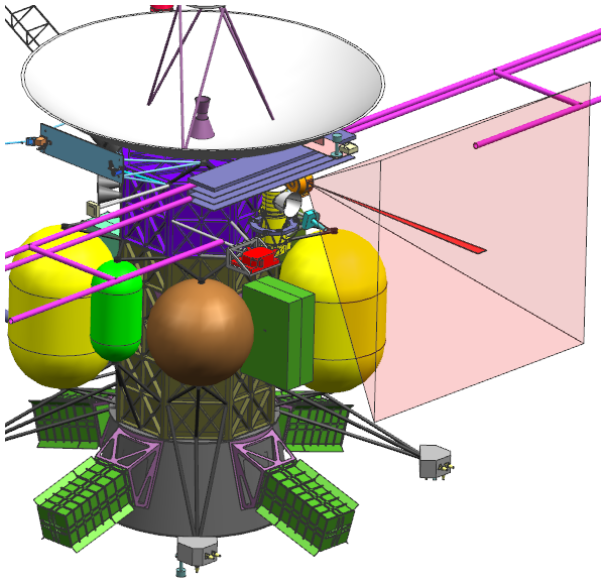




Recon Accommodation



Recon camera has a flip mirror for stereo, imaging ±15° around nadir



Thermal Imager FOV

Enhanced Clipper Mass Margin

Additions:

- Magnetometer and Boom
- Langmuir Probes
- Gravity Science Antenna
- Recon Camera
- Thermal Imager

Reductions:

- Neutral Mass Spectrometer
- Subsystem mass estimate improvement
- Propellant due to improved analysis

Net result:

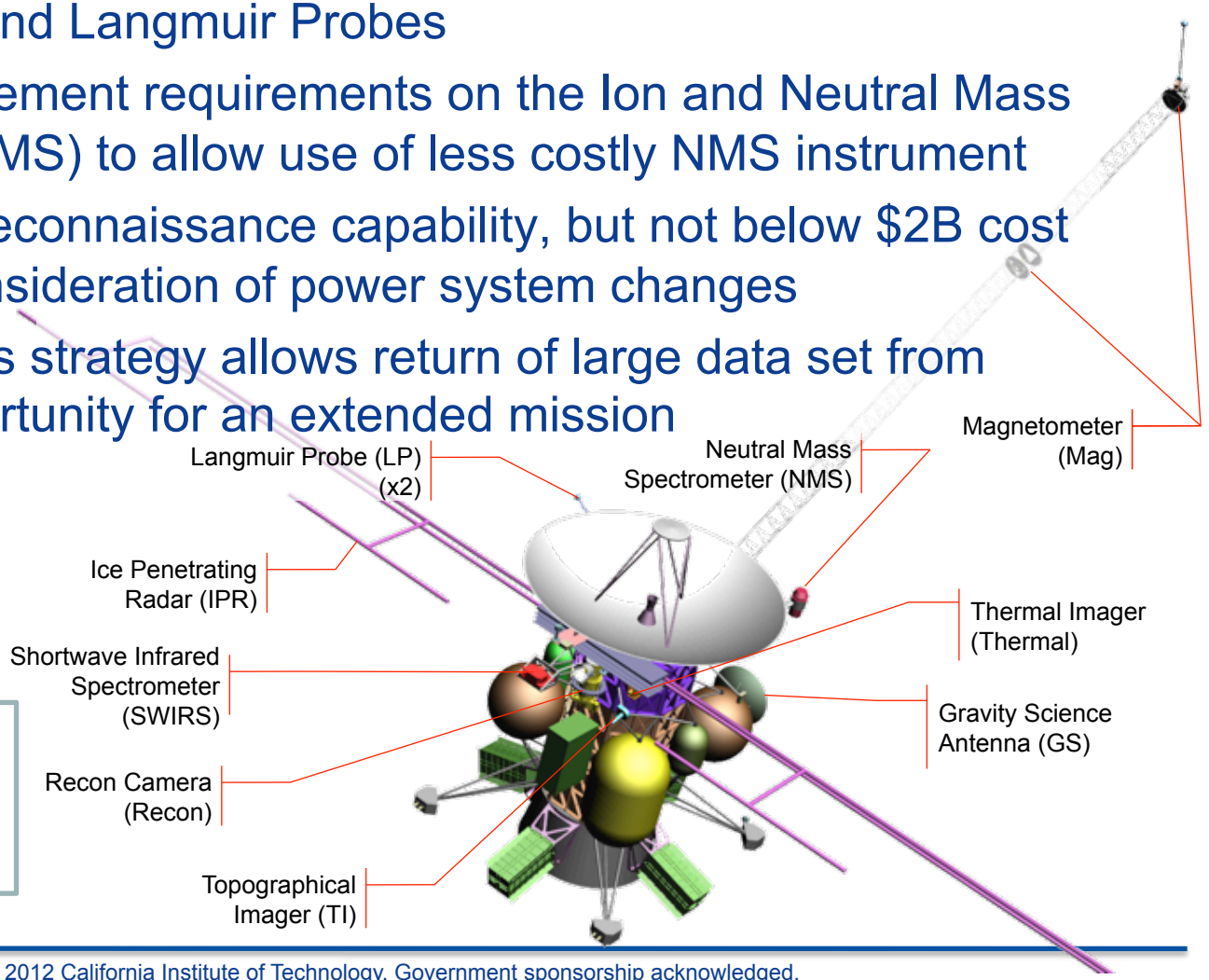
Minimal change in mass margin from May 2012 baseline

Enhanced Clipper Mass Margin

I Gontijo 20 NOV 2012 Enhanced Clipper Mass Margin Report	LAUNCH Flight System Mass, kg			
	CBE	Cont.*	MEV	
Neutral Mass Spectrometer	5	50%	7	
Ice Penetrating Radar	28	50%	42	
ShortWave IR Spectrometer	13	50%	19	
Topographical Imager	3	50%	4	
Magnetometer	3	50%	5	
Two Langmuir Probes (+ booms)	3	50%	4	
Reconnaissance Camera (10 urad)	12	50%	18	
Thermal Imager	6	50%	9	
Payload	72	50%	108	
Power	176	42%	249	
C&DH	15	30%	20	
Telecom	113	34%	152	
Mechanical Structures	712	28%	913	
Thermal Control	48	30%	62	
Propulsion	175	24%	217	
GN&C	37	24%	46	
Harness	68	50%	102	
Radiation Monitor	8	30%	10	
Spacecraft	1353	31%	1771	
Flight System Total Dry	1425	32%	1879	Max Prop
Bipropellant	828		1344	1615
TVC Monopropellant	75		75	75
ACS Monopropellant	40		40	40
Pressurant	6		6	6
Residual and Holdup	24		36	43
Propellant	972		1501	1779
Flight System Total Wet	2396		3381	
Capability (21-Nov-21 VEEGA)	Atlas V 551:		4494	
System Margins				
JPL DVVP (Capability - Max Prop - CBE Dry) / (Capability - Max Prop)			48%	

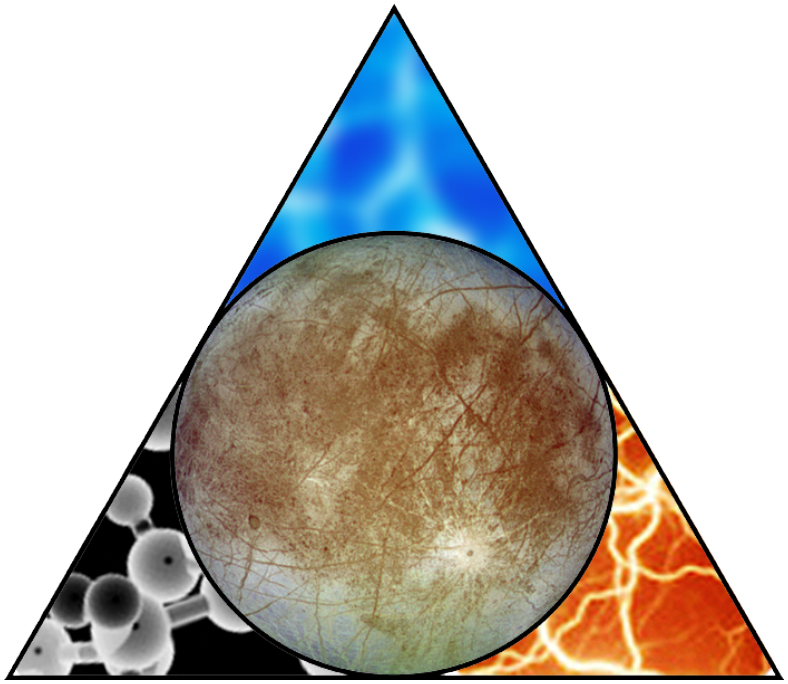
Enhanced Recon Clipper Summary

- Enhanced to address Ocean science objective by adding Magnetometers and Langmuir Probes
- Reduced measurement requirements on the Ion and Neutral Mass Spectrometer (INMS) to allow use of less costly NMS instrument
- Accommodates reconnaissance capability, but not below $2B cost target without consideration of power system changes
- Robust operations strategy allows return of large data set from Europa with opportunity for an extended mission



Technical Margins

48%	40%	62%
Mass	**Power**	**Data**



Europa Enhanced Orbiter

May 2012 Orbiter Concept

Science:

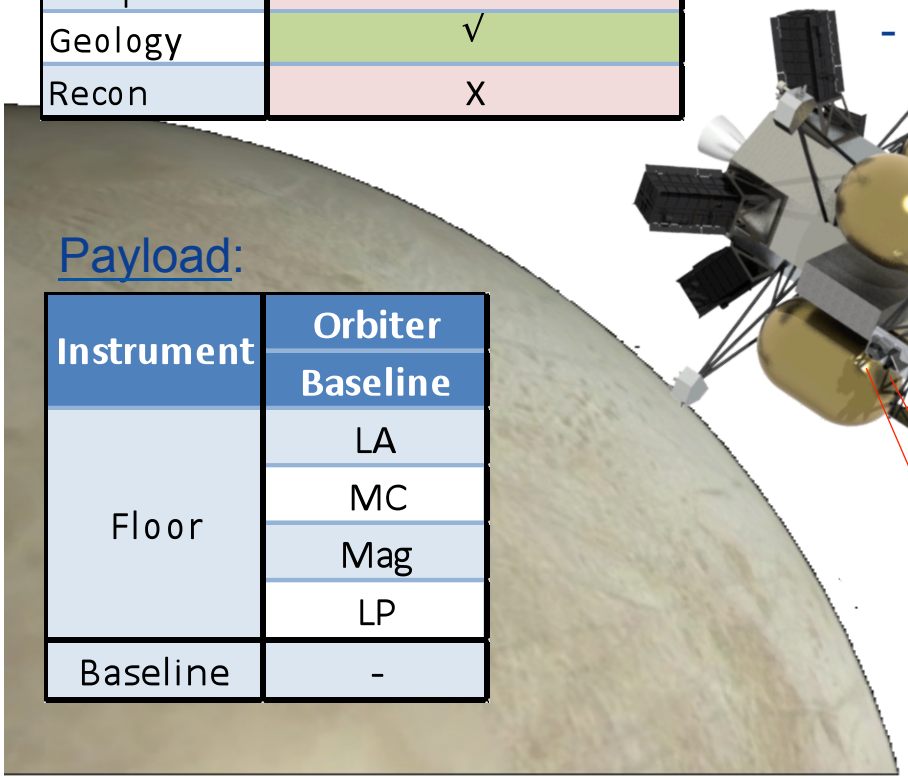
Objective	Orbiter May-12
Ocean	√
Ice Shell	X
Composition	X
Geology	√
Recon	X

Operations Concept:

- 30 days in 100 km near polar orbit about Europa
- Detailed globally mapping, gravity and magnetic field measurements
- Simple repetitive science operations

Payload:

Instrument	Orbiter Baseline
Floor	LA
	MC
	Mag
	LP
Baseline	-



Technical Margins

42%	39%	71%
Mass	**Power**	**Data**

Cost: $1.7B

$FY15, Phases A-E Excl LV

Enhanced Orbiter Key Outcomes

Charge from SDT:

- ✓ Enhance May 2012 Baseline Orbiter Mission to address Ice Shell objectives by adding an Ice Penetrating Radar
- ✗ Enhance May 2012 Baseline Orbiter Mission to address Composition objectives by adding a Shortwave Infrared Spectrometer and Mass Spectrometer
  - *Not accommodated due to cost, mass and orbital geometry conflicts*
- ✓ Accommodate high resolution Reconnaissance Camera and Thermal Imager to enable feed forward reconnaissance data
  - *Thermal Imager not accommodated due to mass and orbital geometry conflicts*

Objective	Orbiter May-12
Ocean	√
Ice Shell	X
Composition	X
Geology	√
Recon	X

Objective	Orbiter Enhanced w Recon
Ocean	√
Ice Shell	√
Composition	X
Geology	√
Recon	√

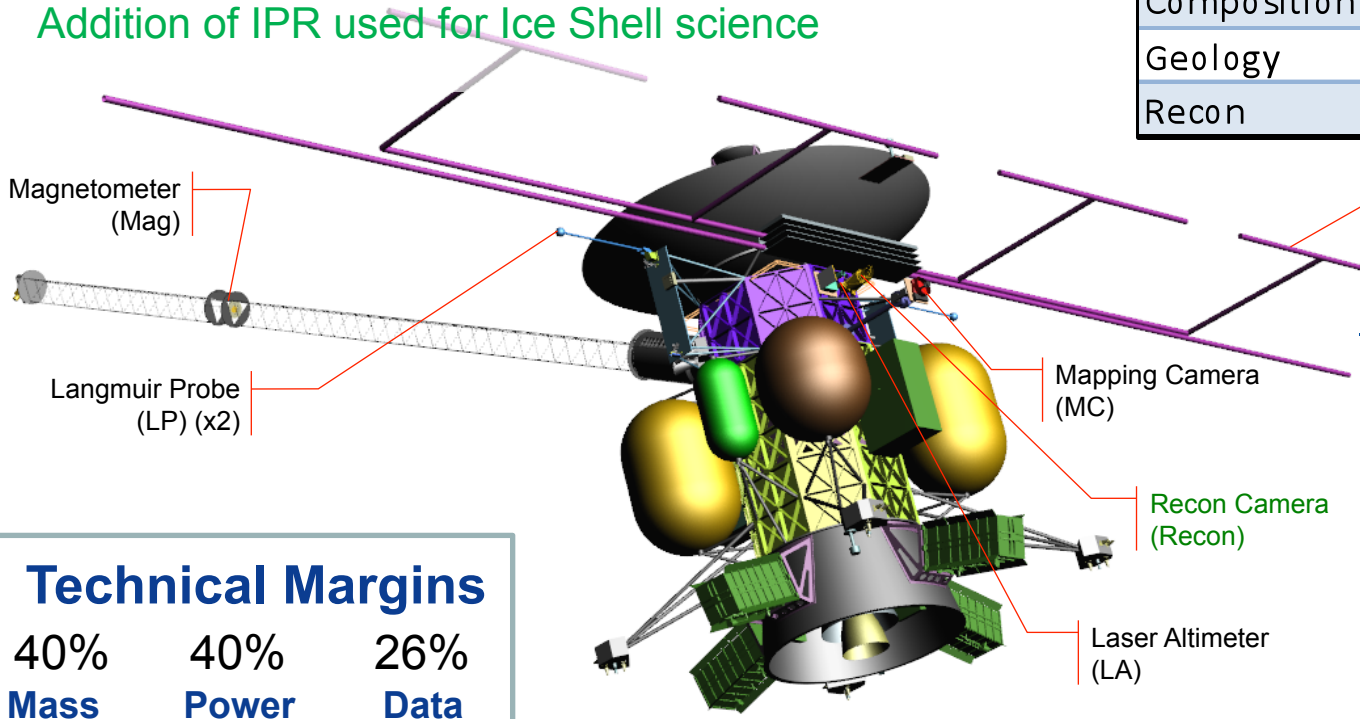
Enhanced Orbiter w/ Recon

Operations Concept:

- 108 days in 100 km near polar orbit about Europa
- Detailed global mapping, gravity and magnetic field measurements
- Simple repetitive science operations
- Addition of IPR used for Ice Shell science

Science:

Objective	Orbiter Enhanced w Recon
Ocean	√
Ice Shell	√
Composition	X
Geology	√
Recon	√



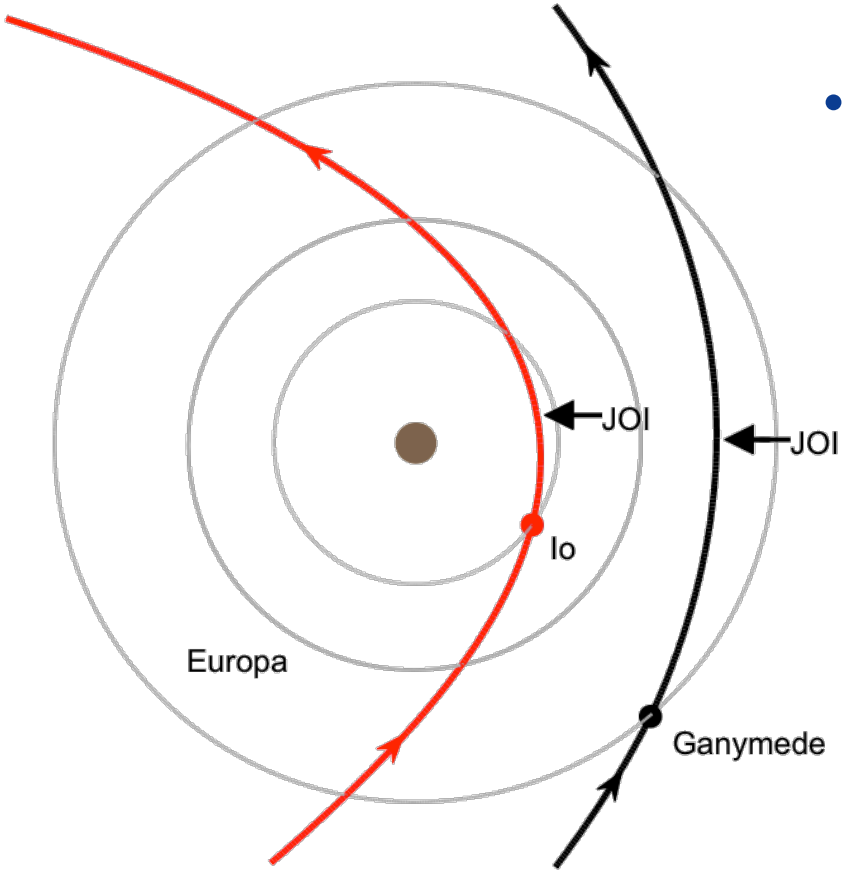
Payload:

Instrument	Orbiter Enh w Recon
Floor	LA
	MC
	Mag
	LP
Baseline	IPR
	Recon

Technical Margins

40%	40%	26%
Mass	**Power**	**Data**

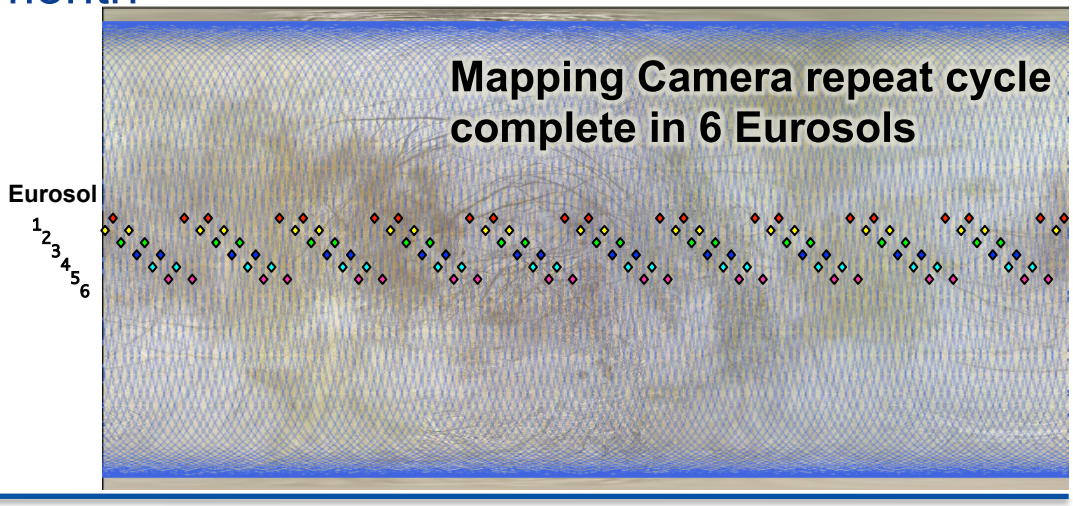
Mass Opportunity via Mission Design



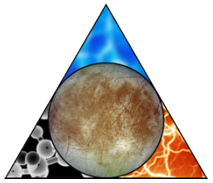
- JOI changed from Ganymede- to Io-assisted
  - Adds 139 kg dry mass capability to offset IPR and additional shielding mass
  - Jupiter tour length grows by a year
  - Higher peak flux, but not during science activities

Europa Orbit

- Same as in the May concept
- ≈100-km circular, polar orbit
  - ≈2-hr period tuned to fill orbit gaps in three successive Eurosols
- High inclination (≈95°)
  - Good mapping coverage
  - Many cross-overs support radar and altimetry measurements
- Initial β angle ≈70° (≈4:40 pm local solar time) increasing ≈6° per month
  - Good lighting for cameras
  - Earth visible continuously for duration of orbital operations



Orbiter Observation Campaign



6 campaigns (assuming a reconnaissance camera)

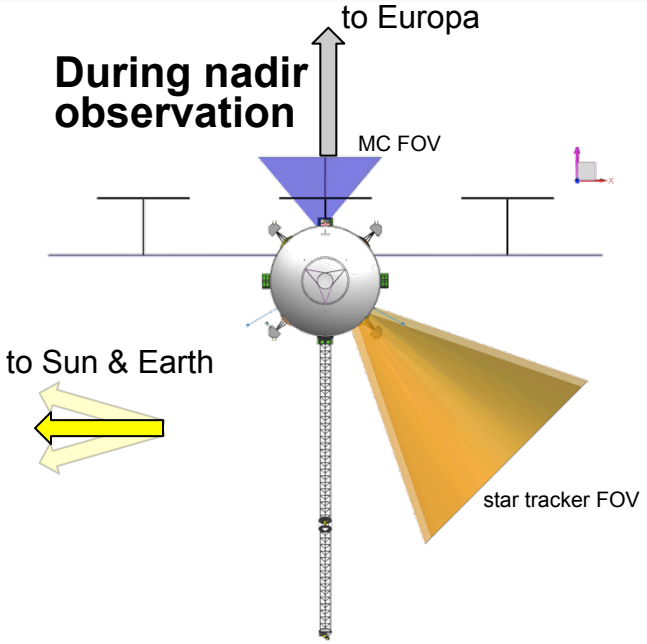
A	**Gravity Science**	Continuous radio Doppler for 1 Eurosol
B	**Stereo Map**	Nearly full stereo map with Mapping Camera First frame of 30 stereo pairs for selected sites with Reconnaissance Camera
R	**Recon Imaging**	Second frame of RC stereo pairs
C	**Radar Profiles**	≥28 1600-km profiles returned at reduced volume, but stored raw for later opportunistic transmission
D	**Raw Radar Targets**	400 km sections selected from each profile and returned raw
E	**Uncommitted**	Either MC color map downlink (collected during B), added raw IPR sections, or reserve

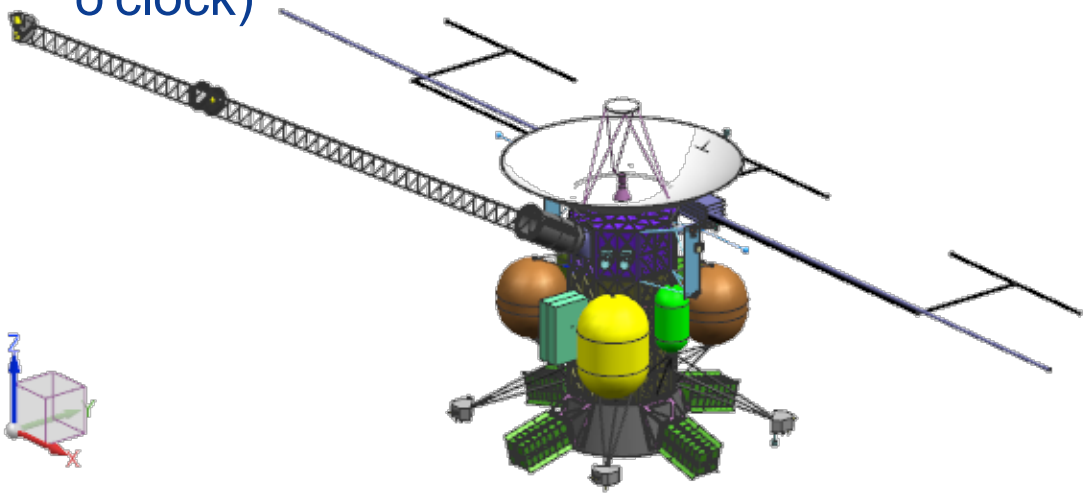
Good coverage for all instruments:

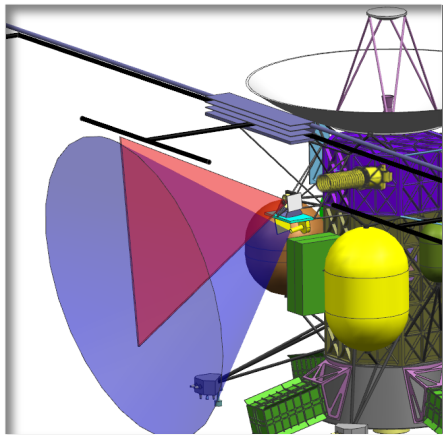
- Complete Mapping Camera coverage to ±85° latitude
- Continuous Magnetometer and Langmuir Probe data in all campaigns
- Mapping and Reconnaissance imaging done quickly to minimize lighting change
- Doppler whenever downlinking data (50% more than May concept)
- Laser Altimeter except during recon image targeting

Mechanical Accommodation

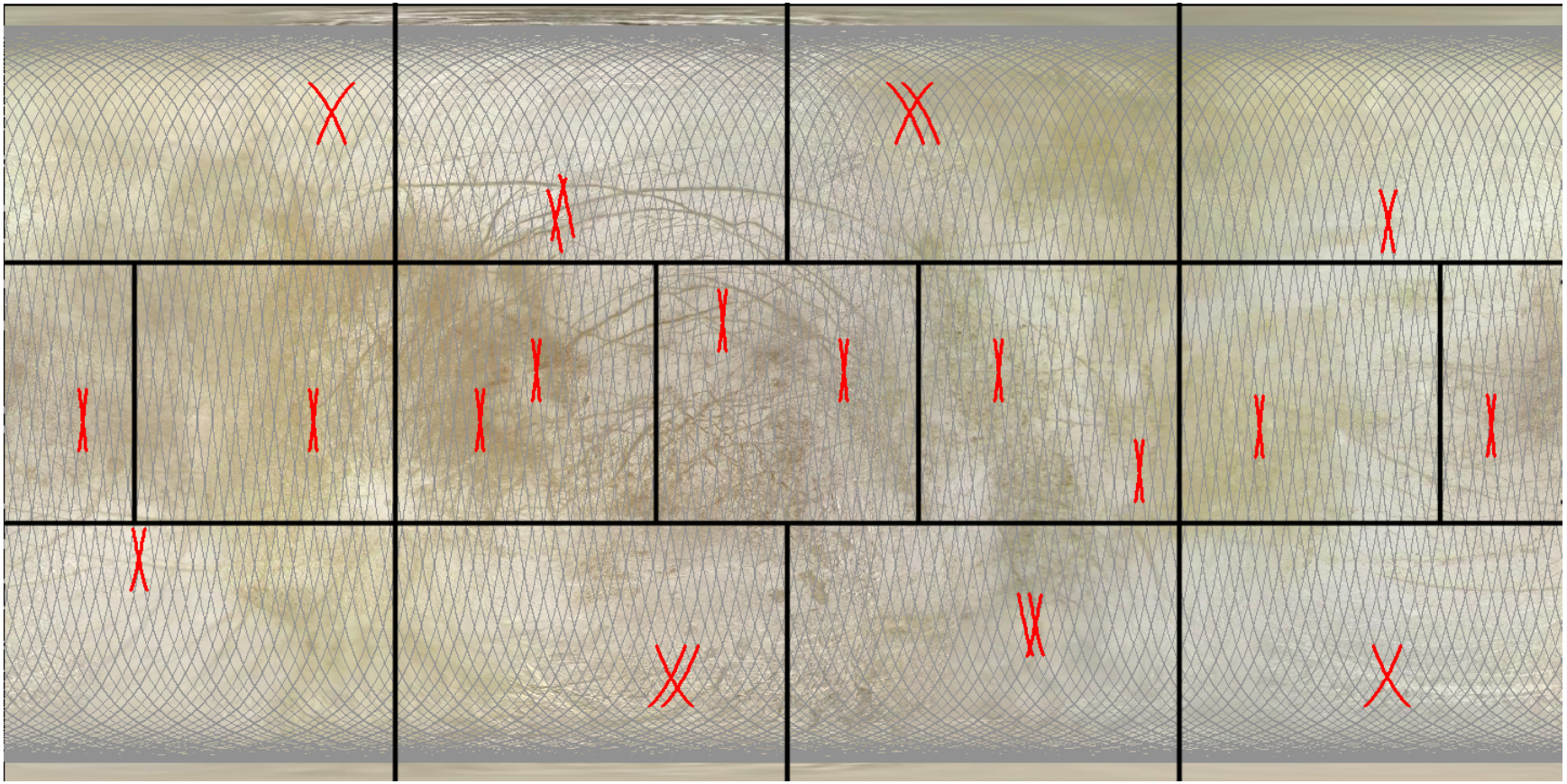
- The May configuration is largely intact
  - Added IPR (antenna pointing +Y)
  - Reconnaissance Camera body-fixed next to Mapping Camera (MC)
  - Body-fixed MC (+Y, stereo toward -Z)
  - LA alone on single-axis gimbal (was two-axis)
  - Langmuir Probe locations (at 4 and 8 o'clock)







Observation Coverage



- High density Laser Altimetry and Mapping Camera coverage
- Ice Penetrating Radar coverage is return bandwidth limited

Data Margins

Campaign	Duration (Eurosols)	DSN Usage	Data Volume Returned	Downlink Data Margin	
A. Gravity Science	1	Full	3 Gb	92%	
B. Stereo Map *with Recon' diversions*	6	1/2	78 Gb	35%	Full stereo map *minus RC gores*
R. Recon Imaging	3	3/4	61 Gb	32%	30 stereo pairs
C. Radar Profiles	2	1/2	29 Gb	26%	28 1600-km profiles Raw data remains on board
D. Raw Radar Targets	14	3/4	293 Gb	30%	20 400-km raw targets
E. Color Map Downlink	3	3/4	60 Gb	33%	

- DSN usage fraction and reserved time are additional margins

Orbiter Mass Margins

Additions:

- Ice Penetrating Radar
- Recon Camera
- Shielding for additional radiation exposure

Reductions:

- Propellant due to Io assisted Jupiter Orbit Insertion
- Subsystem mass estimate improvement

Net result:

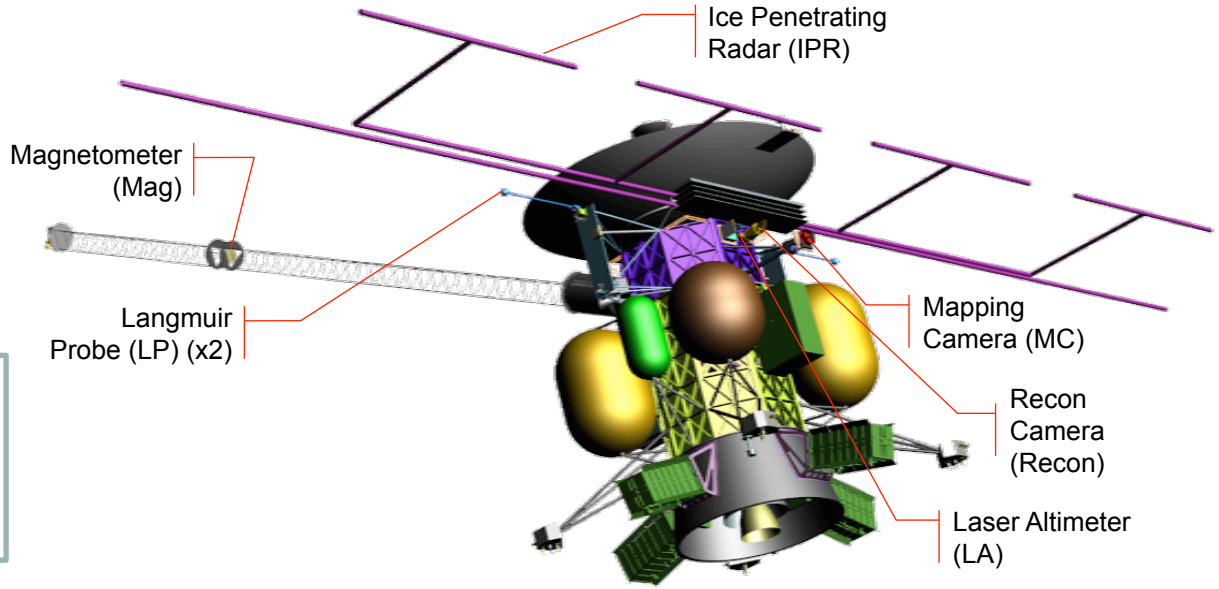
2% reduction in mass margin from May 2012 baseline

Enhanced Orbiter Mass Margin

I Gontijo, 27 NOV 2012 Enhanced Orbiter Mass Margin Report	LAUNCH Flight System Mass, kg			
	CBE	Cont.*	MEV	
Science Electronics Chassis	4	30%	6	
Ice Penetrating Radar	26	50%	39	
Laser Altimeter	5	50%	8	
Mapping Camera	3	50%	4	
Magnetometer	3	50%	5	
Langmuir Probe (Two)	3	50%	4	
Recon Camera (5 urad)	17	50%	25	
Payload	61	49%	91	
Power	175	42%	247	
C&DH	21	30%	27	
Telecom	70	24%	86	
Mechanical Structures	838	29%	1078	
Thermal Control	48	30%	62	
Propulsion	159	23%	195	
GN&C	46	25%	57	
Harness	71	79%	128	
Radiation Monitor	8	30%	10	
Spacecraft	1435	32%	1890	
Flight System Total Dry	1496	32%	1981	Max Prop
Bipropellant	1047		1762	1815
TVC Monopropellant	101		101	101
ACS Monopropellant	40		40	40
Pressurant	6		6	6
Residual and Holdup	30		48	49
Propellant	1223		1956	2010
Flight System Total Wet	2719		3937	
Capability (21-Nov-21 VEEGA)	Atlas V 551:		4494	
System Margins				
JPL DVVP (Capability - Max Prop - CBE Dry) / (Capability - Max Prop)			40%	

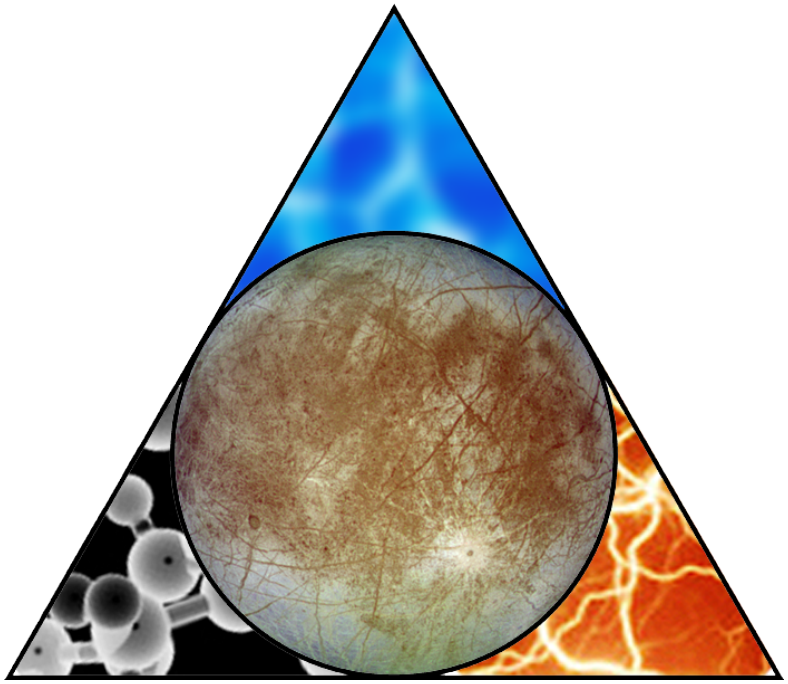
Enhanced Recon Orbiter Summary

- Enhanced to address Ice Shell science objectives by adding Ice Penetrating Radar
- Accommodates Reconnaissance Camera technically, but not below $2B cost target
- Data downlink constraints result in phased orbital operations at Europa, extending the mission from 30 days to 108 days
  - Results in increased shielding mass; offset by Io assisted JOI



Technical Margins

40%	40%	26%
Mass	**Power**	**Data**

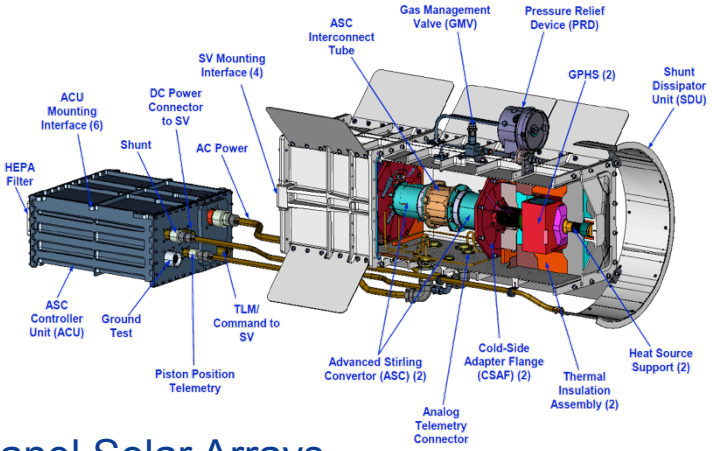


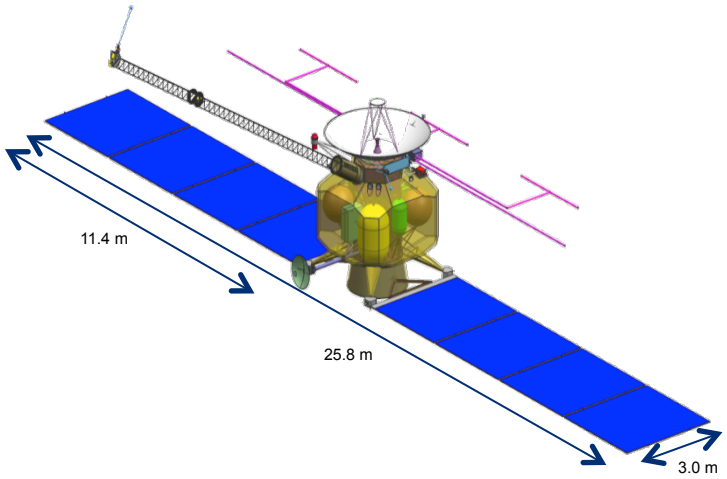
Power System Options

Power System Options

ASRG: Advanced Stirling Radioisotope Generator

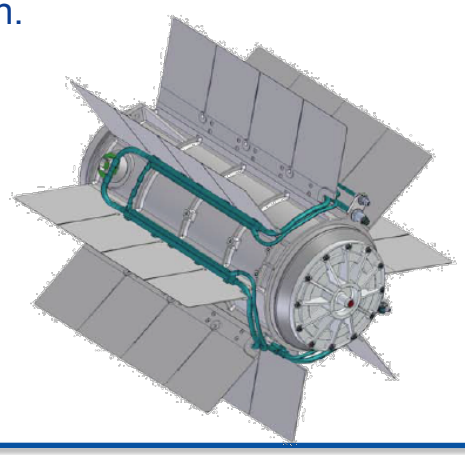
- Recommended by Planetary Decadal Survey
- Technical issues need resolution for compatibility with Europa Mission
- Reliability not yet demonstrated; high per unit cost





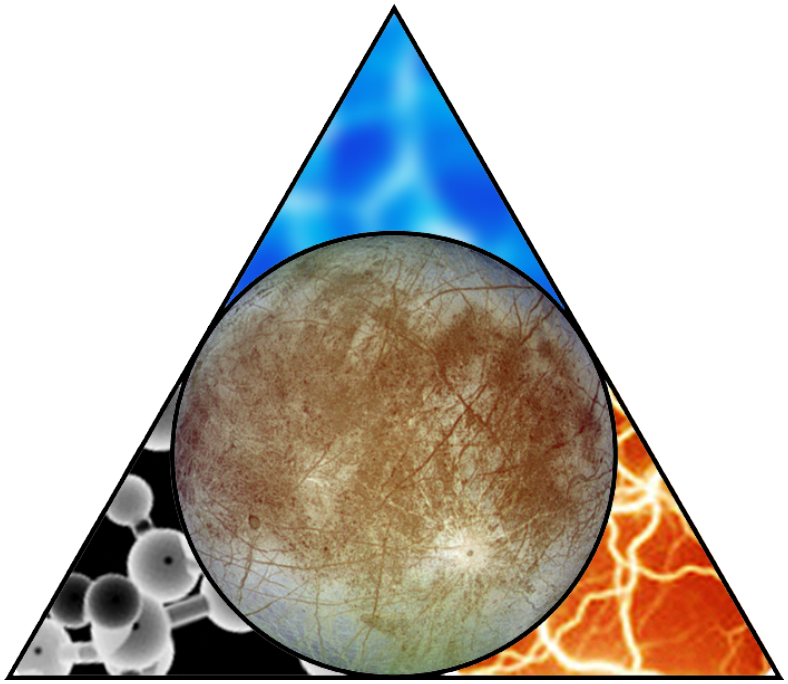
Solar: Foldout Panel Solar Arrays

- Technical issues must be resolved before determining feasibility for Europa Mission
- Reliability uncertain in high radiation environment.
- Highest mass, lowest cost solution.



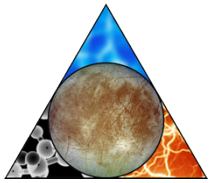
MMRTG: Multi-Mission Radioisotope Thermoelectric Generator

- JEO baseline power source still feasible for redesigned Europa Mission
- Highest ^{238}Pu usage; concern diminished by ^{238}Pu production restart
- Demonstrated high reliability
- Mass and cost impact bounded by Solar and ASRG



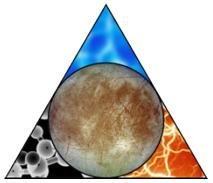
Cost Estimate and Methodology

Cost Methodology



- NICM subsystem mode for instruments
- PRICE-H/SEER for Spacecraft, calibrated to Juno actuals at launch
  - May estimate used Juno estimates from the SIR CADRe and JPL Cost Analysis Database
- SOCM for Operations
- Maintain 40% reserves for Phases A-D costs
- Maintain 20% reserves for Phases E-F

Total Cost for Clipper



Cost: Phases A-F, no LV (FY15$)

Model	May Baseline (ASRG)	May Baseline Aerospace CATE (ASRG)	Clipper w/ Enhanced Science plus Recon (ASRG)
PRICE-H	$1.96B	$2.11B	$2.07B
SEER-H	$1.91B	$2.11B	$2.05B

Key Changes from May Baseline to Current Cost Estimates:

- Updated PRICE/SEER Flight System cost estimates based on October MELs
- Updated instrument cost estimate for IPR based on independent assessment
- Updated instrument cost estimates for all other instruments using NICM (subsystem mode)
- Included additional instrument costs as applicable for Enhanced Science and Recon
- Updated science and operations estimates

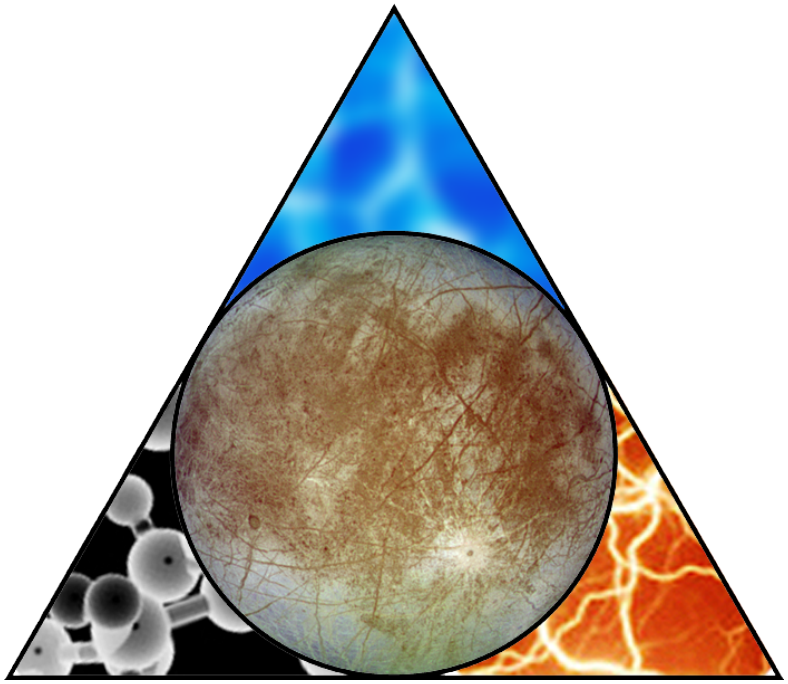
Total Cost for Orbiter

Cost: Phases A-F, no LV (FY15$)

Model	May Baseline (ASRG)	May Baseline Aerospace CATE (ASRG)	Orbiter w/ Enhanced Science plus Recon (ASRG)
PRICE-H	$1.66B	$1.75B	$2.04B
SEER	$1.61B	$1.75B	$2.03B

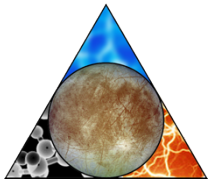
Key Changes from May Baseline to Current Cost Estimates:

- Updated PRICE/SEER Flight System cost estimates based on October MELs
- Updated instrument cost estimate for IPR based on independent assessment
- Updated instrument cost estimates for all other instruments using NICM (subsystem mode)
- Included additional instrument costs as applicable for Enhanced Science and Recon
- Updated science and operations estimates



SDT Recommendation

Enhanced Mission Concepts



- **Clipper**:

  To add some ocean science to the Clipper concept, the SDT recommends:

  – **Ocean, sea floor, and salinity science** (first priority), which can be accomplished by the addition to the payload of a Magnetometer, potentially additional flybys, and a Langmuir probe, and

  – **Ocean confirmation** (second priority), which can be accomplished through gravity science, in the form of a Radio Science experiment

  The enhanced Clipper concept will address the Europa science objectives of Ice shell, Composition, Geology and Ocean

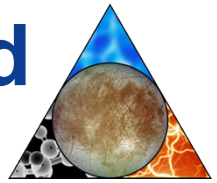
- **Orbiter**:

  The SDT recommends the addition of ice shell science (in the form of a subsurface sounding instrument)

  The enhanced Orbiter concept will address the Europa science objectives of Ocean, ice shell, and geology

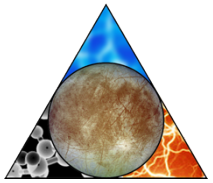
  The SDT is concerned that composition science cannot be accomplished with this enhanced Orbiter concept under the existing cost cap, thus leaving a noticeable gap in Europa science

Programmatic Need for Feed Forward Reconnaissance Data Sets



- The SDT endorses the inclusion of a programmatic reconnaissance capability on the next Europa-focused orbiter or flyby mission, in preparation for a future Europa surface mission
- The notional Clipper payload as conceived would provided an important basis for selecting a scientifically compelling landing site
- The SDT recognizes that any reconnaissance capability involves a cooperative effort between science and engineering with significant input from the science community to be successful

Key Science Questions for Europa

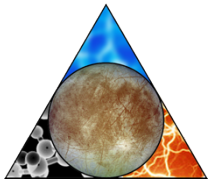


Science Question	Objective	Clipper	Orbiter
1. What are the properties and characteristics of Europa's ocean?	Ocean	✓	✓
2. How thick is the icy shell?	Ice Shell	✓	✓
3. Is there near-surface water within the ice shell?	Ice Shell	✓	✓
4. What is the global distribution of geological features?	Geology	✓	✓
5. Is liquid water involved in surface feature formation?	Geology/Ice Shell	✓	✓
6. Is the icy shell warm and convecting?	Ice Shell	✓	✓
7. What does the red stuff tell us about ocean composition?	Composition	✓	
8. How active is Europa today?	Geology/Ice Shell	✓	✓
9. What is the plasma and radiation environment at Europa?	Ocean/Composition		
10. What is the nature of organics and salts at Europa?	Composition	✓	
11. Is chemical material from depth carried to the surface?	Composition	✓	
12. Is irradiation the principal cause of alteration of Europa's surface material through time?	Composition	✓	

✓ **Enhancements to each Mission concept**

SDT Recommendation

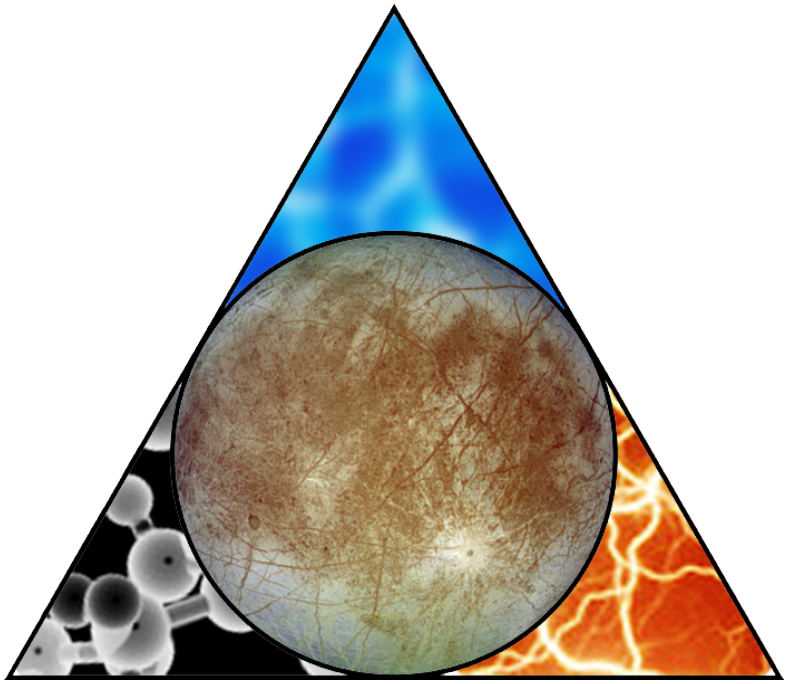
August 2012 meeting



- The SDT reaffirms that the mission concepts described in the May 2012 Report continue to provide robust means to accomplish Europa science with the Clipper ranking above the Orbiter in its ability to achieve high priority Europa science

The enhanced Clipper concept is excellent in meeting the goal of exploring Europa to investigate its habitability

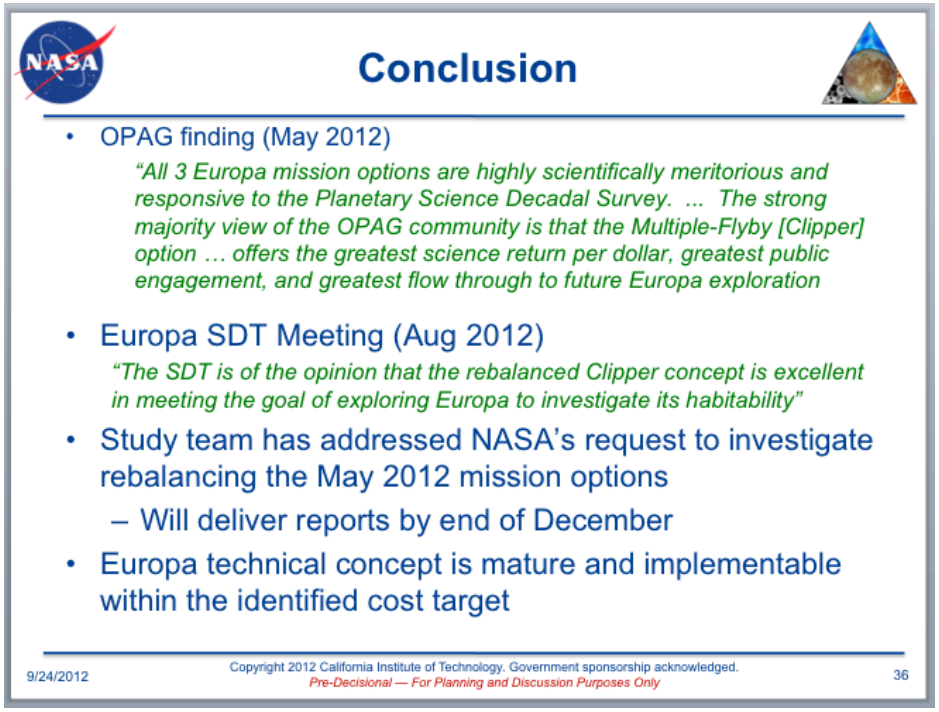
- **This concept will provide significant advancement in key ice shell, composition, geology, and ocean science**
- **The enhanced Clipper is deemed of higher ranking relative to the enhanced Orbiter concept**



Reviews

Europa Presentation to CAPS
9/24/12

- Agenda
  - Where we were left you in May…
  - Europa Summer Study
  - The Enhanced Europa Clipper Mission
  - Engineering Investigations (solar power, SLS, nanosats)
  - SDT Report and Recommendation
  - Summary & Cost

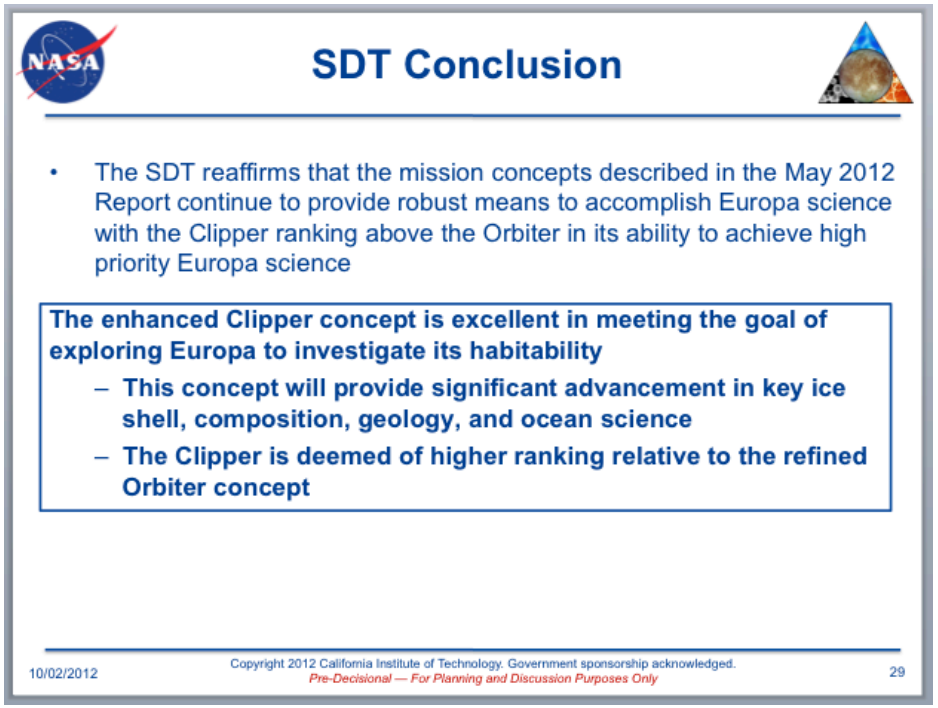


Conclusion

- OPAG finding (May 2012)
  "All 3 Europa mission options are highly scientifically meritorious and responsive to the Planetary Science Decadal Survey. ... The strong majority view of the OPAG community is that the Multiple-Flyby [Clipper] option … offers the greatest science return per dollar, greatest public engagement, and greatest flow through to future Europa exploration
- Europa SDT Meeting (Aug 2012)
  "The SDT is of the opinion that the rebalanced Clipper concept is excellent in meeting the goal of exploring Europa to investigate its habitability"
- Study team has addressed NASA's request to investigate rebalancing the May 2012 mission options
  - Will deliver reports by end of December
- Europa technical concept is mature and implementable within the identified cost target

Europa Presentation to the PSS
10/2/12

- Agenda
  - Recap of the May 2012 Study results
  - Europa Summer Study
  - The Enhanced Orbiter Mission
  - The Enhanced Europa Clipper Mission
  - SDT Report and Recommendation
  - Summary & Cost



SDT Conclusion

- The SDT reaffirms that the mission concepts described in the May 2012 Report continue to provide robust means to accomplish Europa science with the Clipper ranking above the Orbiter in its ability to achieve high priority Europa science

The enhanced Clipper concept is excellent in meeting the goal of exploring Europa to investigate its habitability

- **This concept will provide significant advancement in key ice shell, composition, geology, and ocean science**
- **The Clipper is deemed of higher ranking relative to the refined Orbiter concept**

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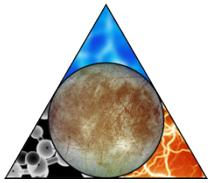
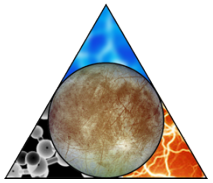
CAPS Assessment on the Europa Study to the PSS (10/3/12)



- The Europa study team has developed excellent orbiter and flyby ("Clipper") concepts that are robust and feasible, and are responsive to the Decadal Survey, the current budget constraints, and the need for balance in the Planetary Program
- The multiple flyby "Clipper" element is favored because it addresses the preponderance of the science objectives laid out in the Decadal Survey
- Independent review by a CATE process (the same used in the Decadal Survey) affirms that the costs for the orbiter and Clipper are credible and that the risk is low
- The Clipper mission has excellent scientific value:
  - Key Europa questions very well addressed
  - No significant overlap with JUICE mission
- Clipper mission concept is well thought out and realistic:
  - Mission length reasonable (32 Europa flybys) and potential for extension
- Radiation issues have been well addressed
- Solar power option is feasible based on Juno experience
- High resolution imaging, if possible without significant growth in cost or complexity, would be an excellent "feed forward" element for a future lander mission

Path Forward



- Proceed to a Preliminary Concept Review (PCR) in the spring of 2013 for the Clipper concept
- A core set of the SDT will act as a Europa Science Advisory Group
  - The SDT has completed its task of defining the science for both the Enhanced Clipper and Enhanced Orbiter concepts
- Interaction with the broad science community will continue—working the concept of "Science from the Europa Clipper" workshop—stay tuned!

EUROPA